COAST GUARD

OFFICE OF RESEARCH & DEVELOPMENT

PROJECT 712999/004

AD715872

EVALUATION

OF

LS-59 XENON FLASHTUBE BEACON

BY

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APPLIED TECHNOLOGY DIVISION

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FINAL REPORT

Prepared for: COMMANDANT (DAT)
U.S. COAST GUARD HEADQUARTERS
WASHINGTON, D.C., 20591

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UNITED STATES COAST GUARD

APPLIED TECHNOLOGY DIVISION

REPORT ON

EVALUATION OF LS-59 XENON FLASHTUBE BEACON

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Date: 1 December 1970

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ABSTRACT

Condenser-discharge beacons capable of operation from battery power supplies on buoys and minor lights offer four distinct advantages over incandescent beacons: (1) increased servicing periods, (2) increased battery life, (3) increased visual effectiveness, and (4) increased "glow ranges" in fog. This report presents the laboratory and field test results of the LS-59 flashtube beacon, as well as a discussion of the potential use of condenser-discharge burst lights as a future base for a maritime signal lighting system.

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1. INTRODUCTION

1.1 Primary Light Sources

In an incandescent lamp, a current passing through a tungsten filament heats the filament to a temperature in excess of 2000°K. At this temperature the filament acts as a radiating source with a large amount of the radiation falling within that portion of the spectrum to which the eye is sensitive. This radiation is considered as visible light. If the temperature is raised sufficiently higher, the filament will melt. Even at its operating temperature, the filament slowly evaporates until some point where a catastrophic failure occurs. In addition to the inevitable failure due to filament evaporation, some of the emitted radiation from the tungsten filament lies outside the visible portion of the spectrum. Thus, the conversion efficiency, or efficacy of lumens/watt is limited also.

An alternative method of producing light is to produce an arc between two electrodes at different electrical potentials. The spectral character of such an arc is largely determined by the gas through which the arc fires. In order to produce a breakdown of the gas to allow the arc, it is necessary to have a large voltage potential between the electrodes. A condenser-discharge lamp, or flashtube, operates on this principle. The energy for the flash is pumped into and stored in a storage capacitor at a high voltage. Then, using an electronic trigger to break down the gas, the stored energy is discharged in an arc producing light.

1.2 Condenser-discharge Flashtubes

The state-of-the-art of condenser-discharge flashtubes is such that a reliable flashtube with a relatively high efficacy presently exists when several hundred volts are discharged through a xenon gas. The flashlength of such a discharge depends upon the length of the path of the arc as well as the voltage potential. The luminous flux produced, integrated over the flash duration, depends upon the voltage and the amount of stored energy, as well as the gas through which the discharge is produced.

1.3 Burst Light

When a series of condenser-discharge flicks are fired rapidly, a burst source is produced. With a repetition rate sufficiently fast, a burst light appears to be continuous to the human eye. Thus, a "multi-flick burst" can be used to increase the flashlength of an otherwise short (several microseconds) "single-flick flash".

1.4 Condenser-discharge Terminology

1.4.1 Flick - a discrete luminous emission of very short duration which

is produced by a gaseous discharge lamp when it is pulsed by a single discharge from a discharge condenser.

1.4.2 Flashtube, or Flashtube Lamp - a gaseous discharge lamp, which when properly fired, produces a flick.

1.4.3 Flashtube Beacon - a beacon consisting of a flashtube and associated electronics.

1.4.4 Burst Flash, or Multi-Flick Flash - a series of flicks fired close enough together in time so as to preclude the appearance of flicker or lapses of light between the flicks within the flash duration of the series of flicks.

1.4.5 Burst Tube, or Burst Tube Lamp - a gaseous discharge lamp, which when properly fired, produces a burst, or multi-flick flash.

1.4.6 Burst Beacon - a beacon consisting of a burst tube and associated electronics.

1.4.7 Energy Levels - Flashtube Beacons have been assigned one of three energy levels:

a. High (H) - 7.2 candela-seconds per flick (flash)

b. Medium (M) - 2.4 candela-seconds per flick (flash)

c. Low (L) - 1.0 candela-seconds per flick (flash)

1.4.8 Designations - Whereas Fl4.0(0.4) designates a flashing incandescent light with a four second period and a 0.4 second flash length, Fl4.0(FT)H designates a flashtube beacon with one flick every four seconds operating on a high energy level, and Fl4.0(0.4S)M would designate a burst beacon with a four second period and a 0.4 second multi-flick flash operating on a medium energy level. Following the same format, QkFl(FT)L designates one low energy flick per second, IQkFl10.0(FT)M designates a group of six medium energy flicks with an interflick spacing of one second and a total period of ten seconds, and GP2-5.0(FT)H designates a group of two high energy flicks one second apart occurring each five seconds. Any other characteristics are easily designated using this same format.

1.4.9 Effective Intensity - The effective intensity is determined by the Blondel-Rey relationship. This expression is used to provide an input into Allard's law to equate lights of different flashlengths which have the same threshold range of detection. In the case of a single flick, the light falls in the Bloch's law asymptote, and the effective

intensity, I_e, is 4.76 (the reciprocal of the Blondel-Rey constant 0.21) times the integrated intensity. This term is used to designate equivalences of lights at or near threshold.

1.4.10 Supra-Threshold Apparent Intensity - It was reported as long ago as 1911 by Blondel and Rey that when two lights of different flashlengths which have the same Effective Intensity (at detection threshold) are viewed at a closer range so as to be well above threshold intensities, that the light with the shorter flashlength appeared brighter than a light with a longer flashlength. Thus, a single flick appears brighter, when viewed at supra-threshold levels, than a longer flashlength light which has the same effective intensity. No numerical descriptor has been assigned to this phenomenon.

2. BACKGROUND

In early 1963 the Coast Guard became considerably disappointed in the nominal one-half year lives of then existing combinations of lamps, lampchangers, flashers, voltage regulators, and daylight controls. In hopes of developing lighting equipment which would require no more than annual maintenance, Engineering Testing and Development Division (now the R&D Applied Technology Division) undertook to investigate condenser-discharge lights for use in aids to navigation. Since, the following models have been tested in the field and/or in the laboratory: (1) one initial demonstration unit; (2) one laboratory visibility research unit, LS-57; (3) six "mariner's evaluation units", LS-58; and (4) twelve "service test" units, LS-59. All were purchased under contract CG-02066-A from EG&G International.

A 1966 Mariner's Evaluation of the LS-58 units in the Third Coast Guard District (Project 3961/04/01) yielded the following conclusions:

a. The quick flash and interrupted quick flash flashtube units observed on buoys were much easier to pick out from among background lights than were incandescent buoy lights.

b. For a flashing incandescent lamp and a flashtube of equal effective intensity, the flashtube is considerably brighter and more conspicuous when viewed at distances appreciably less than maximum visual range (for Fl4.0, QkFl, and GpFl characteristics).

c. At near-threshold viewing for a flashing incandescent lamp and a flashtube of equal effective intensity, when the observers threshold is raised by ambient illumination, the flashtube will be seen at a range when the incandescent light is no longer visible.

d. The type of flashtube evaluated produced a flash equal in effective intensity to a 0.3- to a 0.5-second incandescent flash with roughly two-thirds of the energy consumption of the incandescent lamp.

e. Use of the flashtube with characteristic coding (i.e. group flashing) instead of a color-coded incandescent lamp to indicate lateral significance produces greater effective intensity for a given power consumption.

The mariners evaluation raised the following two questions:

a. Will a line of lighted buoys equipped with flashtube beacons marking one side of a channel, with the lights flashing on the same characteristic but unsynchronized, be an improvement over a similar display using incandescent sources, provided the effective intensities

are nearly equal? (A pilot offered the opinion, after observing QkFl flashtube beacons in New York Harbor, that too many of these signals in one area would be confusing).

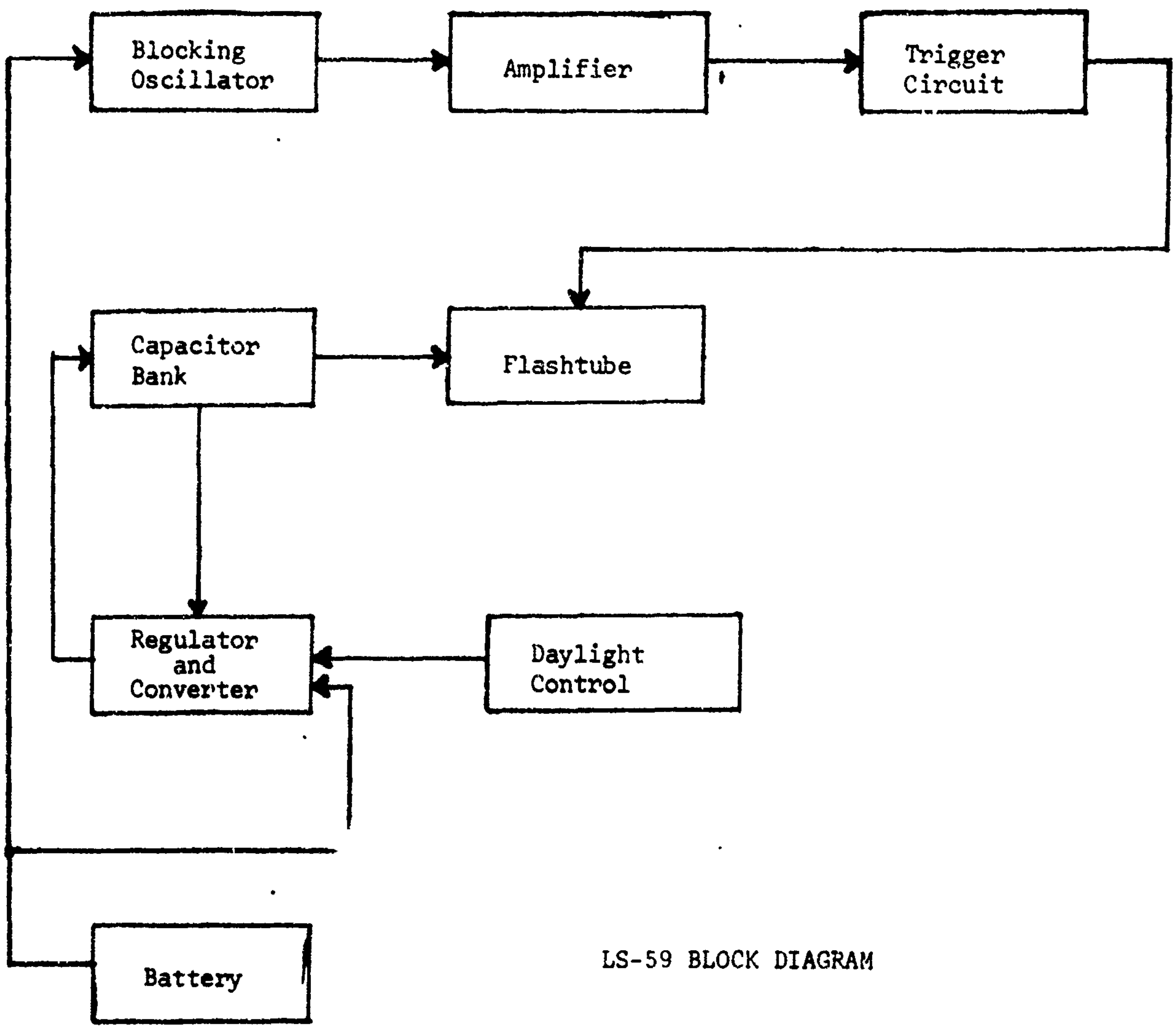
b. Is the F12.5(FT)X characteristic on a flashtube as usable as F14.0(0.4) and F12.5(0.5) characteristics of incandescent lamps now in actual service? It has already been found in the laboratory, as reported in FTDC Report 411 (Project H2-2), that under simulated conditions of relative motion of observer and light, that the two characteristics are equivalent with regard to the time required to take a bearing.

Following the 1966 Mariners Evaluation of the LS-58 units, twelve "service test" LS-59 flashtube beacons were procured as working prototypes for field and laboratory evaluation.

3. DESCRIPTION OF FLASHTUBE BEACON LS-59

A photograph of the LS-59 flashtube beacon is shown as the frontispiece. The beacon electronics is self-contained, needing only to be connected to a 12 volt d.c. source to operate. Energy stored in the 12 volt dc batteries is transferred to the storage capacitors in the beacon by a voltage regulator, solid state oscillator, and a transformer converter. An unconfined arc FX-71 xenon flashtube lamp, handmade by EG&G with a 9mm vertical arc, is connected across the energy storage capacitors. Upon receiving a trigger signal, which causes ionization of the gas within the lamp, the energy from the storage capacitor is dissipated in the lamp in the form of light. The ionized arc within the lamp is in the vertical direction to provide the best source for the Fresnel lenses of marine signal lanterns.

The timing of the system is controlled by a blocking oscillator. For simple flash characteristics, it emits a signal at regular intervals, e.g., each second or each 2.5 seconds. For complex characteristics it contains identical stages equal in number to the period (in seconds) of the characteristic. The stages activate sequentially, one per second, into a common buss. The blocking oscillator either allows signal passage through the amplifier into the trigger circuit or it stops the signal. Therefore, a variety of characteristics firing no closer than one second apart are possible. The EG&G design permits as many as twenty stages or periods as long as twenty seconds. The trigger circuit is a convential SCR-driven type. The converter is a two transistor type to lessen the peak currents to be drawn from the battery supply. Figure 3-1 is a block diagram of the electronic stages of the LS-59.



LS-59 BLOCK DIAGRAM

FIELD TESTING & DEVELOPMENT CENTER
U.S. COAST GUARD YARD
BALTIMORE, MARYLAND 21226

F T D C SKETCH NO 14-70
DATE 17 July 1970
DRAWN BY G. P. Clark

4. LS-59 TEST PROCEDURE

Laboratory tests were performed on LS-59 flashtube beacons at the U.S. Coast Guard Field Testing and Development Center at Curtis Bay, Maryland.

The flash shape and duration were found by detecting the luminous output with an RCA 931-A PMT with a Wratten #106 filter fed to a Tektronix Type 535 S-1 oscilloscope. The waveforms were then photographed.

This same method was used to measure the integrated intensity of one beacon (#009) undergoing lifetime and lumen maintenance tests for the first half of these tests. An EG&G 580-585 Spectroradiometer system was then procured, and all other integrated intensity measurements were made with this instrument in the integrate mode. Calibration was made with an FX-71 xenon flashtube previously calibrated by the National Bureau of Standards.

The lifetest beacon, #009, was powered by batteries and operated on a QkFl(FT)H characteristic. The test was arbitrarily terminated after two years.

The manufacturer also life tested two beacons, #006 and #007, on medium power at accelerated rates of two flicks per second for about a year.

Beacon #013 was used in four NAVAID lanterns for measurements of source-lantern combination integrated intensities in the horizontal plane as well as the vertical divergence.

The spectral composition of beacon #013 was also measured with the spectroradiometer.

Beacons #004 and #009 were used in measurements of power consumption, charging profile, and current drains for each of their characteristics (F12.5(FT)X and QkFl(FT)X), at all three energy levels. A 0.251 ohm resistor was placed in series with the beacon, operating from batteries, and the voltage across the resistor was recorded. This voltage drop profile was converted to a current drain profile.

A variable resistor was used to determine the daylight control on and off resistances of all twelve beacons.

For the field evaluation, LS-59 flashtube beacons were used as operational aids at various locations. Three F12.5(FT)X beacons and one QkFl(FT)M beacon were installed on Ambrose Channel buoys 1A, 3, 5, and 9 respectively on 7 March 1967. It was intended that this string of buoys on one side of the channel would provide insight into the utility of this

mode of operation.

An IQkF110.0(FT)H beacon was used for tests of the ability of the LS-59 to withstand vibrations and shocks on bell buoys. After seven months on Fisherman's Obstruction Lighted Bell Buoy off Sandy Hook, N.J., it was transferred to New Orleans Lightship Replacement Bell Buoy in the Gulf of Mexico, and then to Calcasieu Channel Lighted Bell Buoy 46.

A GP2+5.0(FT)H was installed on Joe Curtis 735.8 Mile light on the Mississippi River at Memphis, Tennessee. On this station, the flashtube beacon is in competition with a complexly lighted background.

Two installations of F12.5(FT)H beacons were made, in Seattle and on the St. Mary's River, with the intention of evaluating the potential of the LS-59 in fog.

Table 4-1 summarizes the status of the LS-59 flashtube beacons upon publication of this report.

Table 4-1-Location of LS-59 Flashtube Beacons

Serial No.	Characteristic	Location
002	F12.5(FT)L	Ambrose 3
003	F12.5(FT)L	Ambrose 5
004	F12.5(FT)H	St. Mary's River
005	IQKF110.0(FT)H	Calcasieu Channel
006	QkF1(FT)L	Ambrose 9
007	F12.5(FT)H	Seattle
008	QkF1(FT)L	Field Testing and Development Center
009	QkF1(FT)H	Field Testing and Development Center
010	F12.5(FT)M	Ambrose 1A
011	F12.5(FT)M	Spare for Ambrose 1A
012	GP2+5.0(FT)H	A/N School
013	GP1/3-8.0(FT)L	A/N School

Note: GP1/3-8.0(FT) is the flashtube equivalent to a short/long (Morse Code Alpha). The sequence is one flick, two second eclipse, three flicks with one second interflick spacing, four second eclipse.

5. LS-59 TEST RESULTS

5.1 Laboratory Results

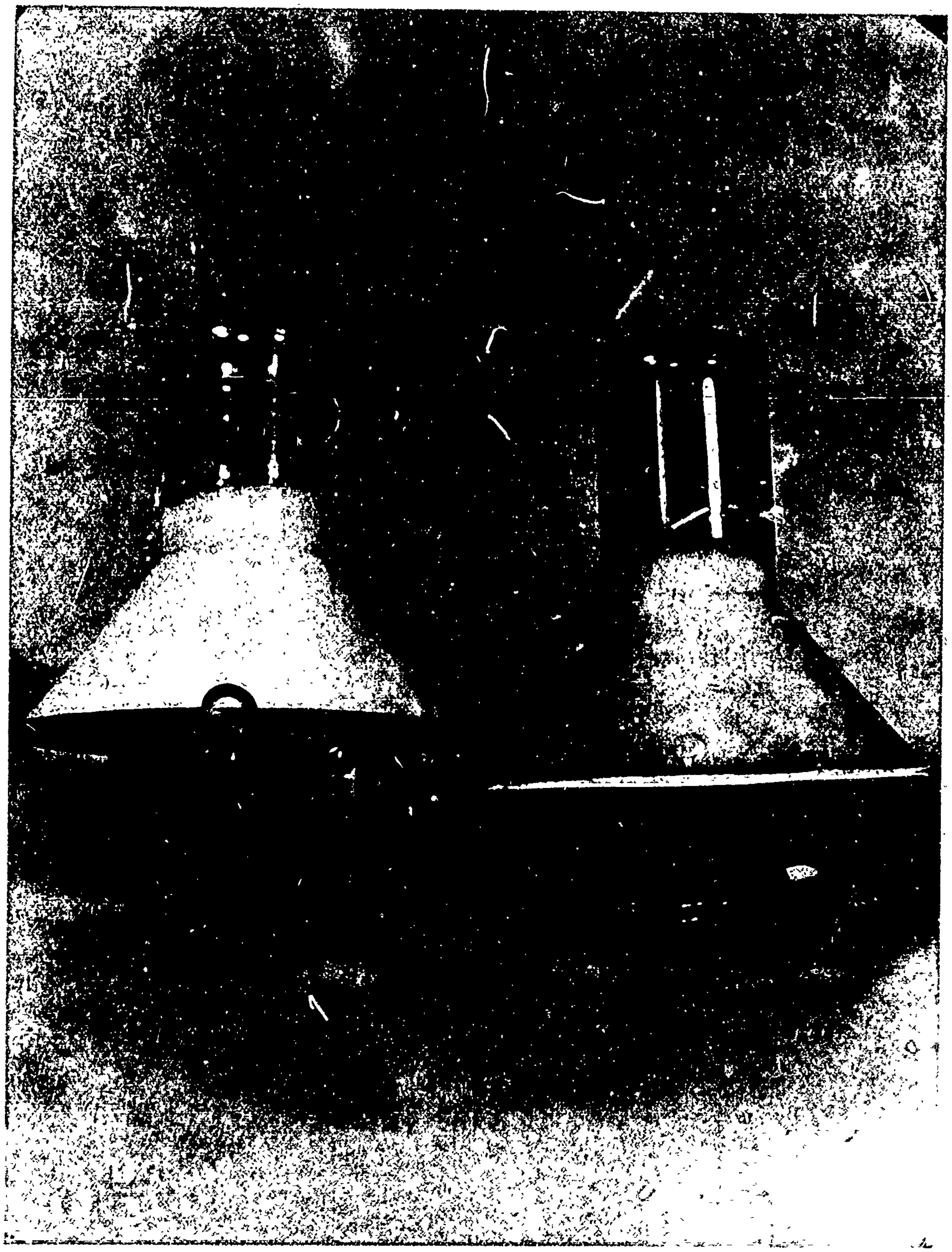
5.1.1 Temporal Flick Profile - The shapes of all temporal profiles photographed on the oscilloscope were essentially the same. An Intensity vs. Time curve can be found in Appendix A. This curve was drawn with two microseconds to the inch and an integrated area of twenty square inches. For a low energy 1.0 cd-sec. flick, the ordinate scale is 25,000 cd/in, and the peak is 190,000 cd. A medium energy 2.4 cd-sec. flick has a peak of 456,000 cd, and a high energy 7.2 cd-sec. flick has a peak of 1,368,000 cd.

5.1.2 Effective Intensity - The effective intensity is calculated from the integrated intensity and the flashlength through the Blondel-Rey relationship, $I_e = \frac{\int Idt}{a+t}$. The "constant" a conventionally used is that found by Blondel and Rey in their experiments, namely a = 0.21 sec. Some theoretical discussion is given to this constant in Appendix D. This Appendix also discusses the integration limits for the condenser-discharge flick and the flashlength. These are taken to be the entire integrated intensity and a flashlength negligible compared to a. Thus, $I_e = \frac{\int Idt}{a+t} \approx \frac{\int Idt}{.21} = 4.76 \int Idt$.

Measured integrated intensities and the corresponding effective intensities are listed in Table 5-3.

5.1.3 Life Tests - Beacon #009 was subjected to life testing at FTDC, operating on a QkFl(FT)H characteristic for approximately a two-year period. The integrated intensity was periodically measured during these 66½ million flicks. The output remained nearly constant for the first 15 million flicks, then decreased to about twenty percent of the original intensity over the next 25 million flicks. The output from 40 million until arbitrary termination at 66½ million remained relatively constant. A plot of Integrated Intensity vs. Time is given in Appendix A. Photograph 5-1 shows this flashtube after 66½ million flicks as well as an unused flashtube. The flash rate during this period remained relatively constant with the exception of a marked decrease and inconsistancy as the batteries used approached depletion. No malfunctions were noted in the LS-59 when the life test was arbitrarily terminated.

The manufacturer life tested two LS-59 beacons, #006 and #007, both drawing 2.52 watt-seconds per flick at rates of two flicks per second. They report reductions in output to 47% after 63½ million flicks on #006 and to 77% after 73½ million flicks on #007. At those points, their tests were arbitrarily terminated. Their data is also



Photograph 5-1

FX-71 Flashtubes - New and Used
(66-1/2 million high energy flicks)

Table 5-1 Useful Lifetimes of FX-71 Flashtubes

Energy Level	Energy (watt-sec)	Number of flicks to approximately 55% of initial luminous flux (Flashtube life)
High - H	4.8	25 million
(EG&G Test)	2.52	50 million
Medium - M	1.6	75 million
Low - L	0.64	200 million

plotted in Appendix A.

On the basis of these limited results, a first order approximation may be made that the number of flicks to 50% integrated intensity is inversely proportional to the power dissipated per flick. The decrease in luminous output is due to the darkening of the flashtube envelope and will be somewhat variable. Catastrophic failure generally occurs when electrode redeposites on the base cause an arc to be drawn across the base. This catastrophic failure evidently occurs long after the flashtube intensity is reduced to the 50% level.

Since catastrophic failure of incandescent filaments in marine signal lamps usually occurs with a luminous output of 50-60% of the initial output, the useful life of a flashtube lamp can be defined in a similar manner at 55 ± 5% of its initial luminous flux. Using this criteria, Table 5-1 lists the approximate useful lifetimes of FX-71 flashtube lamps on the LS-59 flashtube beacon.

5.1.4 NAVAID Photometry - The unconfined vertical arc dimension was specified as 9mm. This dimension on beacon #013 was measured as 8.5mm. Vertical divergence profiles were measured using this flashtube beacon in four NAVAID lanterns. Plots of this complete photometric data are given in Appendix A. Table 5-2 summarizes this data.

Table 5-2 Navaid Photometry Resume

Lantern	Optic/source ratio	50% Vertical Divergence
ESNA 155mm buoy lantern	8.4	6.5°
200mm pressed glass buoy lantern	5.3	5.4°
ESNA 250mm lantern	8.5	4.1°
Tidelands 300mm lantern	12.0	3.2°

5.1.5 Spectral Content - The spectral content of beacon #013 was measured on all three energy levels. A plot of Luminous Intensity (a photometric quantity including the spectral sensitivity of the eye) vs. Wavelength, for high and medium power, is given in Appendix A. Also shown on this plot is the spectral sensitivity of the eye, which would be the luminous intensity of an equal-energy white light. The differences in the spectral content of the high and medium energy flicks shown on the plot are in part real, but not completely accurate. The energy content at the long wavelengths was low enough to tax the sensitivity of the spectroradiometer severely. The low energy spectral content was similar at the short wavelengths, but too weak to be measured at the long wavelengths. The chromaticity of this blue-white light lies in close proximity to the 15,000°K black body chromaticity, and may be considered to be a 15,000°K black body metamer.

Due to the preponderance of short wavelength content, and the dearth of long wavelength content, very high color factors result when used with a standard green lens or shade, and very low color factors result with red lenses or shades. Furthermore, when used with standard green lenses and shades, the chromaticity plots on the "blue" side of signal green, outside the signal green chromaticity limits. Since neither an acceptable signal green nor a sufficiently intense signal red are produced, the LS-59 should not be color coded.

5.1.6 Power Requirements - The storage capacitors in the LS-59 beacons are charged to 800 volts. The energy stored is given by $\frac{1}{2}CV^2$. The capacitances used for the three power levels are 2, 5, and 15 microfarads, yielding storages of 0.64, 1.6, and 4.8 joules (watt-seconds). The efficacies to 1.0, 2.55, and 7.2 candela-seconds per flick are all approximately 1.5. However, the Coast Guards interests are concerned with the total efficiency of the beacon, which includes to energy expended in operating the electronics in the beacon. Two beacons, #004 and #009, were measured for the total luminous efficiency at all three power levels. This data is given in Table 5-3, which can be safely generalized by assuming an efficacy of 1.0 candela-sec./watt-sec.

Table 5-3 Power and Light Measurements

Unit	Level	Period sec.	Rated E_{in} joules	Measured E_{in} joules	Rated E_{out} cd-sec	Measured E_{out} cd-sec	Efficacy	Max R-16 ohms
004	L	2.6	0.64	0.91	1.00	1.22	1.34	40K
004	M	2.6	1.7	2.63	2.55	2.65	1.01	15K
004	H	2.6	4.8	6.62	7.20	7.5	1.13	1.5K
009	L	1.1	0.64	0.87	1.00	1.02	1.18	60K
009	M	1.1	1.7	2.03	2.55	2.60	1.28	20K
009	H	1.1	4.8	6.30	7.20	7.4	1.18	3K

The power consumption of the LS-59 essentially consists of two parts: (1) an idle current, and (2) a charging current. The current is drawn in discrete bursts having exponential rise and fall shapes so flat as to almost appear triangular. During the charging period, these spikes are larger and more numerous than during the idle period between charging and firing. The resistor in the charging circuit, R-16, determines the charging rate. R-16 was varied on these two beacons on all energy levels to determine its effect on total energy consumption, peak current, and average charging current levels. This information is of interest since battery power units have limitations on the rates of discharge if the full ampere-hour capacity is to be available. The maximum values of R-16 which permitted fully charging of the storage capacitors just before firing are listed in Table 5-3. These values vary with the flash rate (characteristic) as well as from unit to unit.

For large values of R-16, the discrete energy spikes are far enough apart in time to return to zero before the start of the ensuing spike. As R-16 is lowered, the start of each charging spike occurs prior to the termination of the previous spike, yielding essentially a DC plus ripple shape in the charging profile. This is also accompanied by a large initial peak value at the onset of charging. The peak of this spike, which has a very short duration, was not measured. In the interest of minimizing both this peak, as well as the charging level, R-16 should take on a value enough to separate the charging spikes. No consistant tendancies were noted in the total energy drawn as R-16 was varied.

The storage capacitors in the LS-59 are Sprague Electric 2KV paper mylar capacitors operated at 800 volts. Although past EG&G experience had indicated that a long-term degradation can be expected, no checks were made on the storage capacitors. In the life test of #009, there was no storage capacitor failure even though the beacon was operated over a period in excess of twice the useful life of the flashtube lamp. Expected useful capacitor life cannot be accurately predicted at this time. Continued future use may be expected to provide some indication of this at a much later date.

5.1.7 Daylight Controls - The LS-59 purchase description required beacon turn-on before the resistance across the daylight control terminals exceeded 50 Kohms and turn-off before the resistance falls below 10 Kohms. Table 5-4 gives the "turn-on" and "turn-off" values measured on ten of the LS-59 units. Three points stand out: (1) The resistance values increase with voltage (2) the turn-off resistance values are nominally 0.5 Kohms less than the turn-on levels and (3) the values corresponding to the average voltage readings in the range 12-13 volts are nominally 15 Kohms. Appendix C, Daylight Control Effect on the Accuracy of Power Unit Lifetime Predictions, shows that all three are undesirable from a lifetime prediction standpoint. It

TABLE 5-4

RESISTANCE (Kohm) FOR DAYLIGHT CONTROL OPERATION

Unit	Characteristic	VOLTAGE 11 ON	11 OFF	12 ON	12 OFF	15 ON	15 OFF	18 ON	18 OFF
002	Fl 2.5(FT)M	11K	10.8	14.5	14	24.5	23.9	34.4	34.0
003	Fl 2.5(FT)M	12.7	12.2	16.2	15.6	25.7	25.3	35.8	35.0
004	Fl 2.5(FT)M	13.0	12.7	16.5	16.1	26.1	25.9	36.6	36.2
005	IQkFl 10.0(FT)M	11.7	11.4	15.0	14.6	24.8	24.4	35.0	34.7
006	QkFl(FT)M	11.15	11.14	14.40	14.38	25.2	24.1	35.0	34.4
009	QkFl(FT)H	10.49	10.43	13.7	13.5	23.0	22.9	33.0	32.1
010	Fl 2.5(FT)H	12.0	11.4	15.0	14.8	25.6	25.0	35.6	35.4
011	Fl 2.5(FT)H	11.7	11.2	15.1	14.4	24.7	24.3	34.7	34.5
012	GP2,5.0(FT)H	11.3	11.0	14.5	14.2	24.2	23.9	35.1	34.8
013	GP1/3-8.0(FT)H	11.1	10.7	14.2	14.0	23.8	23.3	33.4	33.0
	Greatest	.6		.7		1.1		.9	
	Least	.01		.02		.1		.2	
	Average	.317		.352		.460		.450	

NOTE: #012 and 013 yield false characteristics near Daylight Control ON and OFF points.

recommends: (1) Resistance values that do not fluctuate as a function of closed circuit voltage (CCV). i.e., power unit life (2) a minimum difference between the turn-on and turn-off values of 5 Kohm (3) a maximum turn-on resistance of 40 Kohms. These values have been incorporated in the flashtube purchase description recommended in Appendix B.

5.1.8 Temperature, Shock, Immersion and Humidity Testing
Under contract CG-14,455-A, EG&G, Inc. performed simulated environmental tests to determine whether LS-59 design had any weaknesses or inherent failure modes. The LS-59 (Serial No. 007) was exposed first to temperature testing, then consecutively to shock, humidity, and immersion testing. Functional testing, modified functional testing, and operation testing were introduced, as necessary, throughout the environmental testing to substantiate the unit's electrical and performance condition. Visual inspection of the unit was made throughout the environmental testing to establish mechanical integrity. Visual inspection was concerned primarily with examination of the flashtube assembly and the upper housing, the seal between the upper and lower housing, and with the mounting elements and other exposed surfaces.

In its Technical Report No. B3502 of 3 February, 1967 EG&G concluded that "the LS-59 Medium Power Navigational Beacon has no inherent design weaknesses or failure modes. The unit should withstand regular exposure to temperature extremes of from 0°F to 125°F without ill effect. Further, such shock and random immersion as it would be exposed to should cause no ill effects. However, should the unit be exposed as it is presently fabricated to very high humidity for extended periods of time while in a non-operational condition, some deterioration of performance might be expected.

"The problem with humidity experienced with the unit tested appears to be readily cured. The application of a coating of Dow Corning 630 silicone to the printed circuit boards within the unit would preclude the formation of any leakage paths in the event that any moisture were introduced into the housing. This step is recommended for all subsequent units. It is further recommended that better control be exercised as regards the quality of seals made between the upper and lower housing units. These steps should insure full qualification of future units through all environmental testing."

5.1.9 Reliability - There were no failures of equipment components, other than the flashtube darkening during the life test, during the laboratory phase of the testing. However, prior to delivery of the twelve beacons to the Coast Guard, EG&G performed an electronic stress analysis to locate components which might cause unreliable operation. This analysis was made with an input voltage of 18 volts. The storage capacitors had the highest rates of individual components, although

the entire timing circuitry has been calculated to have a lower reliability than the storage capacitors on all characteristics. For an average of 13 hours of operation a day, a very pessimistic annual reliability has been calculated. Table 5-5 lists, by characteristic, timing circuitry, storage capacitor, and overall electronic predicted "safe" reliabilities. This has also been converted to an aid-day ratio reliability.

5.2 Field Evaluation Results

5.2.1 Use on Channels - One pilot from Interport Pilots, Associates, Inc., after using the flashtube beacons on Ambrose Channel Buoys 1A, 3, 5, and 9 for six months stated "They should never be placed as they have been, namely, in a line where one may not easily be distinguished from the others. We believe strongly that they should be used on turns and beginnings of channels, to mark that turn, and to indicate a difference from the conventional buoy." Another pilot stated "I would suggest that these type buoys only be used on turns and entrances to channels so that mariners can improve service to the vessel at the most dangerous locations of navigation." The president of the Sandy Hook Pilots Benevolent Association stated "...the men advocate the locations of the buoys might be changed so as to have them located at the entrance of the (Ambrose) channel and at the turns."

5.2.2 Reduced Effective Intensity on Ambrose Channel - Table 5-6 compares the effective intensities of the final LS-59 flashtube beacons on Ambrose Channel with that of the former incandescent lights. The reduction in the intensities was at the request of the local pilots who had voiced strong objection to the brightness of the LS-59's which originally had effective intensities comparable to the former incandescent lights. The preference of these users was for a reduction in effective intensity on all but the entrance buoy.

Three points must be taken into account before attempting to evaluate this preference of the mariner to reduce the intensity of these buoys: (1) When headed out to sea, the background is essentially dark, whereas the shoreline of Staten Island lies ahead when inbound, (2) There is a two-station range on Staten Island, and Ambrose Offshore Tower and the mid-channel entrance buoy act similarly when outbound, and (3) The buoys in Ambrose Channel are gated over the full extent of the region in this evaluation. The only clearcut conclusion that can be made is that the dislike, or annoyance, of the close-aboard "flashbulb" effect on side markers is of more concern than the luminous range when the mariner is also provided a range and conventional flashing incandescent red lights on the other side of the channel. The other aids present preclude the validity of attempting to define a tradeoff between luminous range and suprathreshold conspicuity,

TABLE 5-5 Computed Reliabilities

Characteristic	Reliability Timing Circuit	Storage Capacitor	Electronic	AID-DAY Ratio
QkF1(FT)H	0.86	0.93	0.74	.9992
QkF1(FT)M	0.86	0.93	0.80	.9994
QkF1(FT)L	0.86	0.93	0.80	.9994
F12.5(FT)H	0.94	0.97	0.89	.9997
F12.5(FT)M	0.94	0.97	0.92	.9998
F12.5(FT)L	0.94	0.97	0.92	.9998
F14.0(FT)H	0.96	0.98	0.93	.9998
F14.0(FT)M	0.96	0.98	0.95	.9999
F14.0(FT)L	0.96	0.98	0.95	.9999
IQkF110.0(FT)H	0.70	0.96	0.64	.9988
IQkF110.0(FT)M	0.70	0.96	0.67	.9989
IQkF110.0(FT)L	0.70	0.96	0.67	.9989
GP2-5.0(FT)H	0.76	0.97	0.72	.9991
GP2-5.0(FT)M	0.76	0.97	0.74	.9992
GP2-5.0(FT)L	0.76	0.97	0.74	.9992
GP1/3-8.0(FT)H	0.74	0.96	0.68	.9990
GP1/3-8.0(FT)M	0.74	0.96	0.71	.9991
GP1/3-8.0(FT)L	0.74	0.96	0.71	.9991

Note: The middle three columns indicate the ratio of the number of such beacons still operating at the end of one year to the number at the beginning The last column assumes one day replacement of outages and indicates the ratio of the total number of days operational (total available minus the number of outages) to the total number possible had no outages occurred.

TABLE 5-6 Effective Intensities on Ambrose Channel

Ambrose Channel Lighted Buoy	Effective Intensity Incandescent (before 3/7/67)	Effective Intensity LS-59 (after 9/7/68)
1A	110 cd.	100 cd.
3	65	40
5	110	40
9	150	40

since the range provides direction information and the red lights on the gated side markers satisfy the mariners distance requirements. The "flashbulb" effect will be discussed in Chapter 6 and Appendix D. The pilots have indicated, however, that the flashtube source on turns and entrances is a good idea. It is felt that at these locations, the "flashbulb" annoyance is a reminder that the channel is changing.

5.2.3 Shock and Vibration - The IQkF110.0(FT)H beacon, #005 was originally installed on Fisherman's Obstruction Lighted Bell Buoy off Sandy Hook, New Jersey. After satisfactory performance there for nine months, it was used for one and one-half months on the New Orleans Lightship Replacement Bell Buoy. The tests were continued in the Gulf of Mexico on Calcasieu Channel Lighted Bell Buoy 46, where this beacon lasted five months before failing. This high-energy, complex-characteristic beacon produced approximately 15 million flicks before failing while used exclusively on lighted bell buoys. The reason for beacon failure was a flashtube lamp failure.

5.2.4 Complexly Lighted Backgrounds - On 31 July 1967, the GP2-5.0(FT)H beacon, #012, was installed on Joe Curtis 735.2 Mile Light on the Mississippi River in the midst of the background lights of Memphis, Tennessee. After three months operation, the Second District assessed its operation as follows:

> "All responses received to date have been favorable. Most commented on its ability to be effectively distinguished from surrounding background lighting regardless of color. A few mariners observed that the light could be improved if the flash period could be made longer. The short flash period causes some difficulty in lining up the light. This complaint has been mild in nature and not considered to be too significant (at this location). As a rule, the pilots use the reflective daymarks to steer on once they have located the lights.
>
> "It is the opinion of this command that the Xenon Flashtube light does have application on the Western Rivers and is effective as a navigational light in areas with bright background lighting."

5.2.5 Effectiveness in Fog - Beacon #007, operating on a F12.5(FT)H characteristic was tested at three locations in the Seattle area. The mariners comments were mostly directed towards the better conspicuity of the flashtube source against lighted backgrounds, and the difficulty in taking visual bearings. Even so, "At short ranges, the loom of the flashtube has been reported visible under low visibility conditions when incandescent lamps in the immediate area were not." Commander (oan), Thirteenth Coast Guard District further feels "Because of this property, it is believed that a flashtube might be developed into a suitable short range fog signal, especially for those areas in which noise must be limited."

5.2.6 Comparison of F12.5(FT)X and F14.0(0.4) Characteristics - Figure 22 of Field Testing and Development Center Report 411, Project H2-2, shows that these two characteristics are equivalent in the time required to take a bearing on them, i.e., when a gyro repeater (as seen through a pelorus) serves to stabilize the observers line of sight. This conclusion, however, cannot validly be extended to the situation of observations without the pelorus. The Ambrose Channel investigation, which included such a change in characteristics on three buoys, produced no comments from the mariners about this change. However, the pilots on the St. Mary's River expressed discontentment with the short flash length. The reduction in eclipse time from 3.6 to 2.5 seconds can be expected to reduce the extent of fixation drift between flashes, but the flashtube flick is too short to permit fixation during the flash.

5.2.7 Increased Power Unit Lifetimes - The recharge period for Ambrose Channel Lighted Buoy 9 increased from 275 days to 2700 days when the LS-59 was installed. This can be broken down as follows:

a.	155mm Lantern vice 200mm Lantern	125 days
b.	40 vice 150 Equivalent Candela	950 days
c.	Increased efficacy of LS-59	1350 days

Of course, had this buoy had a 40 candela output with a 155mm lantern before the conversion, the recharge period would have been 1350 days, yielding in this case a doubling of the recharge period for the same equivalent intensity.

Actual performance cannot easily be compared to predicted lifetimes for all the LS-59's in the field. Some beacons were moved around from station to station, one buoy collided with and swamped, and some still on the first set of batteries. However, on Ambrose Channel Lighted Buoy 3, with one 12SJ power unit, a rated life of 875 days was predicted for F12.5(FT)M characteristic. These batteries lasted 750 days, 570 days on F12.(FT)M and 180 days on F12.5(FT)L. This prediction was about 30% optimistic. On Ambrose 1A, with two 12SJ's and one month with a 1.15

amp incandescent lamp before LS-59 installation, a battery lifetime of 425 days again fell about 30% short of the predicted 570 days. At Memphis, the GP2.5.0(FT)H lasted 280 days instead of 297 predicted for two 2SJ's and two 3SJ's. From the limited amount of good field data collected thus far, it can only be stated that the power unit lifetime, for the same effective intensity, is increased by fifty to one-hundred percent when changing from an incandescent source to the LS-59 flashtube beacon. In other words, the LS-59, in order to produce an equivalent effective intensity, will draw from one-half to two-thirds the power as an incandescent lamp.

5.2.8 Reliability - The reliability of the LS-59 flashtube beacon has thus far been upheld in the field tests. On Ambrose Channel, for example, after three full years of operation, three of the four LS-59's have not been serviced, while the fourth operated for two and a half years before the buoy was struck in a collision with a ship. The F12.5(FT)H in Seattle is still operating after one and a half years. The IQkF110.0 (FT)H on the bell buoys has already been noted as lasting fifteen months before flashtube lamp failure. The GP2-5.0(FT)H in Memphis failed after nine months. The F12.5(FT)H on the St. Mary's River is still operating after six months.

In summary, the only natural catastrophic failures in the field evaluation occured on the two beacons with the complex characteristics, and both of these were operating at high power levels. These lasted through 5.7 and 15 million flicks. The six beacons with the simple characteristics have lasted through as much as 47 million flicks without a natural catastrophic failure.

6. DISCUSSION

6.1 Advantages and Disadvantages of Single Flick Flashtube Beacons

6.1.1 Advantages - The following advantages exist for single flick condenser discharge flashtubes:

a. The extremely short flash length of a flick lies deep in the Bloch's Law asymptote of the Blondel-Rey relationship, and hence provides a higher effective intensity than a longer flash of equal integrated intensity. The temporal distribution of the light, therefore, maximizes the luminous range for a given integrated intensity (an equal amount of light).

b. The conversion efficiency at the light source is greater than that of an incandescent lamp.

c. The lamp life reliability of a single FX-71 flashtube lamp is several times greater than the combined lamp life of six incandescent lamps, and about ten times as long.

d. The flashtube flick is very distinctive or conspicuous against actual complexly lighted marine backgrounds.

e. The periphery of the retina (scotopic vision) is far more sensitive to the blue-white color of a flashtube than the reddish white of an incandescent lamp which is equally detectable in photopic (central) vision.

f. The electronic circuitry of the flashtube beacon has a power drain comparable to that of the combined flasher-lampchanger combination now in use.

The result of these advantages is a more reliable light source which for the same luminous range is more conspicuous and more economical (longer service periods for both batteries and lamps).

6.1.2 Disadvantages - The following disadvantages exist for the LS-59:

a. The spectral content of the xenon flash is generally low at long wavelengths. A very low transmittance would result from a filter capable of producing an acceptable signal red. An incandescent source would produce a more economical red light.

b. If the flashtube were color coded, the very short flashlength makes color naming (proper color identification) extremely difficult.

c. The short flashlength makes fixation all but impossible on dark backgrounds without the aid of fixation cues.

d. If the flash occurs during a normal saccadic movement of the eye, the "jump effect" is present and the light is seen in the wrong place (somewhere that it isn't and not where it is) in the field of view.

e. When close aboard at very high supra-threshold levels, the apparent brightness is so high that the annoyance of the "flashbulb effect" is confusing and can be detrimental to the preservation of night vision.

6.1.3 Limitations caused by disadvantages - LS-59 flashtubes should not be color coded. This limitation is imposed by disadvantages a. and b. above. Disadvantages c., d., and e, are closely related in origin, and place limitations on the use of LS-59's depending upon the particular usage in mind rather than as a general restriction. The LS-59 should not be used on range lights. At one point on the St. Marys River, the LS-59 was used as the front range light with a fixed rear light. The aspect of the two lights in space was found difficult to judge and not at all liked by the pilots. The use on channel buoys was not found to be acceptable to mariners, although its conspicuity close aboard finds favor at obstructions, channel entrances, and turn buoys. In this respect, when vessels are apt to come into very close proximity to a buoy, the LS-59 should be used only if the buoy station indicates a warning to stay clear, or that the buoy marks other than the continuity of the side of a straight segment of a channel. One vessel Master on the Lakes concluded that the flashtube "is a menace to navigation and not an aid to navigation" when passing close aboard.

6.2 Potential Advantages of Burst Beacons
A burst beacon permits several variations worth considering which may minimize the disadvantages of the LS-59 while still closely meeting the advantages. By producing a short flash containing several flicks, the peak intensity can be reduced by a factor approximately equal to the number of flicks, which could reduce the "flashbulb effect". In so doing, the flashlength is effectively made longer, and if sufficiently long the observer will be capable of fixating during the flash. The jump effect, if still present, will be apparent and capable of coding. The longer flash may also permit eventual color coding if and when efficient flashtubes of much lower color temperature are producible. It is conceivable that the state-of-the-art of flashtube technology will advance to this stage using gases other than xenon, different operating voltages, and/or different internal pressures in the flashtube. At sufficiently high luminances as when

appreciably above threshold, the repetition rate will be below critical flicker frequency (CFF) causing a multi-flick burst to appear flickering within the flash. This distinctive characteristic could conceivably aid in the conspicuity of a light against a complexly lighted background. The necessary flashlength should be found to be no longer than the shortest flashlengths now used with incandescent lamps. Although departure from the Bloch's law asymptote would occur, the lack of a current surge found with incandescent lamps will benefit the efficacy of the burst beacon, particularly at the flashlengths of our shortest incandescent flashes which have the largest surge factors. Preliminary research into multi-flick bursts has already begun in other projects to investigate these expected advantages, but there are no findings to report at this writing.

6.3 Uses of Condenser-discharge Light Sources

Characteristics and uses can be set in a definitive manner for flashtube beacons and tentatively for burst beacons.

6.3.1 Flashtube beacons - To maintain consistancy with presently used meanings of various characteristics on buoys, the following uses of flashtube beacon characteristics falls into place:

a. Side Markers (red buoys and black buoys) - simple slow flashing not to exceed thirty flashes per minute - Fl2.5(FT)X - Flashtube beacons should not be used on channels other than the entrance buoy, but may be used on red buoys and black buoys not marking the side of a channel.

b. Turns, Constrictions, Wrecks, and Obstructions - a simple fast flashing characteristic of at least 60 flashes per minute - QkFl(FT)X - when vessels must pass close aboard, the energy level should be minimal, preferably low.

c. Junctions and Bifurcations - an interrupted fast flashing characteristic repeated about 6 times per minute - IQkFl(FT)X - a low energy level is preferred since these buoys invariably lie on the sides of channels.

d. Mid-channel Buoys - A Morse Code "A" characteristic (Short/Long) repeated about 8 times per minute - GPl/3-8.0(FT)X is the flashtube beacon version of this characteristic.

e. Minor lights ashore - Any characteristic normally used on a minor light may be used with the flashtube beacon source. Flashtube beacons should not, however, be used on range lights.

6.3.2 Burst Beacons - It is anticipated that burst beacons will be programable to any standard characteristic with the exception that the flash lengths will be shorter, and pending future work they will be

useful anywhere without restrictions other than normal use of the characteristics.

6.4 Standard Energy Levels

The standard energy levels in the LS-59 for the energy dissipated in the flicks are calculated from $\frac{1}{2}CV^2$. Operating at 800 volts, the capacitances of 2, 5, and 15 microfarads, the stored energies are 0.64, 1.6, and 4.8 joules for the low, medium, and high levels respectively. The entire beacon draws approximately 1.0, 2.5, and 7.0 joules to operate at these energy levels. The conversion to luminous energy yields flashes with integrated intensities of 1.0, 2.4, and 7.2 cd-sec. per flick.

6.4.1 Considerations based upon Battery Capacities - Consider sun switch operation, using the standard 14 hrs/day on time, and 1000 AH battery capacity. Table 6-1 lists the service period of such a power source for all LS-59 characteristics. Some small variations can be expected between individual units. The current drain during the charge periods can be taken to be about 0.8 amps, with an initial very short spike about 2-4 times that value. The choice of batteries and number of banks should be based upon the 0.8 amp drain for charging periods of 0.1, 0.25, and 0.75 seconds for the three energy levels. The initial spike can be disregarded.

6.4.2 Considerations based upon range requirements - Table 6-2 summarizes the luminous ranges on three backgrounds for various transmissivities for common flashing characteristics for both the LS-59 energy levels (3) and five common lamp sizes. There is a good mix between the flashtube effective intensities and the incandescent lamp effective intensities, although the flashtubes never exceed the maximum intensities achievable with incandescent lamps. An increase of 33% for the flashtubes could be achieved by raising the high energy from 15 to 20 microfarad storage capacitance. This is the largest

TABLE 6-1 Nominal Service Periods

Characteristic	Battery Service Period for 1000AH at 14 hrs/day		
	Low Power	Medium Power	High Power
QkFl(FT)X	860 days	340 days	120 days
IQkFl(FT)X	1430	570	200
GP1/3-8.0(FT)X	1720	680	240
F12.5(FT)X	3430	860	300
GP2-5.0(FT)X	3430	860	300

ß

TABLE 6-2 Luminous Ranges for Buoys

Candela	Incandescent Characteristic & Lamp size QkFl(0.3)	Fl4(0.4)	Fl2.5(0.5)	MoA	Dark Background T=.9	T=.7	T=.5	T=.3	T=.1	Lumin Minor T=.9
155mm Lantern										
0-49	FT/0.55	FT	FT	FT	6.2	4.0	3.0	2.2	1.4	2.5
50-99	.77	.55/.77	.55/.77	.55/.77	8.0	5.0	3.6	2.5	1.6	3.3
100-149	FT/1.15	1.15/FT	FT	1.15/FT	9.0	5.6	3.9	2.8	1.7	3.9
150-199			1.15		10.0	5.9	4.1	2.9	1.8	4.3
200-299	FT/2.03/3.05		FT	FT/2.03/3.05	11.2	6.5	4.4	3.1	2.0	5.1
300-399			2.03/3.05		12.4	7.0	4.7	3.3	2.1	5.7
250mm lantern										
0-49	FT	FT	FT	FT	6.2	4.0	3.0	2.2	1.4	2.5
50-99	.55/.77	.55			8.0	5.0	3.6	2.5	1.6	3.3
100-149	FT	FT/.77	FT/.55/.77		9.0	5.6	3.9	2.8	1.7	3.9
150-199	1.15				10.0	5.9	4.1	2.9	1.8	4.3
200-299		1.15	1.15		11.2	6.5	4.4	3.1	2.0	5.1
300-399	FT/2.03/3.05	FT/2.03	FT		12.4	7.0	4.7	3.3	2.1	5.7
400-499		3.05	2.03		13.1	7.3	4.9	3.4	2.1	6.2
500-599			3.05		14.0	7.6	5.0	3.5	2.2	6.6
300mm lantern										
50-99	FT	FT	FT		8.0	5.0	3.6	2.5	1.6	3.3
100-149	FT/.55	FT/.55	FT/.55		9.0	5.6	3.9	2.8	1.7	3.9
150-199	.77	.77	.77		10.0	5.9	4.1	2.9	1.8	4.3
200-299	1.15	1.15	1.15		11.2	6.5	4.4	3.1	2.0	5.1
300-399	FT/2.03	FT	FT		12.4	7.0	4.7	3.3	2.1	5.7
400-499	3.05				13.1	7.3	4.9	3.4	2.1	6.2
500-599		2.03/3.05	2.03		14.0	7.6	5.0	3.5	2.2	6.6
600-799			3.05		15.0	8.0	5.3	3.7	2.3	7.3

Allowing for a 15% degradation of atmospheric transmittance due to air polluti
CG-250-37 was collected, these transmissivities are met or exceeded as shown b

T=0.9 met or exceeded 2-3% of the time
T=0.7 met or exceeded 65-70% of the time (T=0.
T=0.5 met or exceeded about 85% of the time
T=0.3 met or exceeded about 92% of the time
T=0.1 met or exceeded about 95% of the time

LE 6-2 Luminous Ranges for Buoys

Lamp size MoA	Luminous Range Dark Background					Minor Background					City Background				
	T=.9	T=.7	T=.5	T=.3	T=.1	T=.9	T=.7	T=.5	T=.3	T=.1	T=.9	T=.7	T=.5	T=.3	T=.1
FT	6.2	4.0	3.0	2.2	1.4	2.5	1.9	1.6	1.3	0.9	0.8	0.7	0.7	0.6	0.5
.55/.77	8.0	5.0	3.6	2.5	1.6	3.3	2.5	2.0	1.5	1.1	1.2	1.0	0.9	0.7	0.6
1.15/FT	9.0	5.6	3.9	2.8	1.7	3.9	2.8	2.2	1.7	1.1	1.4	1.2	1.0	0.9	0.7
	10.0	5.9	4.1	2.9	1.8	4.3	3.0	2.4	1.8	1.2	1.6	1.3	1.2	0.9	0.7
03/3.05	11.2	6.5	4.4	3.1	2.0	5.1	3.5	2.7	2.0	1.3	1.9	1.6	1.3	1.1	0.8
	12.4	7.0	4.7	3.3	2.1	5.7	3.8	2.9	2.1	1.4	2.2	1.8	1.4	1.2	0.9
FT	6.2	4.0	3.0	2.2	1.4	2.5	1.9	1.6	1.3	0.9	0.8	0.7	0.7	0.6	0.5
	8.0	5.0	3.6	2.5	1.6	3.3	2.5	2.0	1.5	1.1	1.2	1.0	0.9	0.7	0.6
	9.0	5.6	3.9	2.8	1.7	3.9	2.8	2.2	1.7	1.1	1.4	1.2	1.0	0.9	0.7
	10.0	5.9	4.1	2.9	1.8	4.3	3.0	2.4	1.8	1.2	1.6	1.3	1.2	0.9	0.7
	11.2	6.5	4.4	3.1	2.0	5.1	3.5	2.7	2.0	1.3	1.9	1.6	1.3	1.1	0.8
	12.4	7.0	4.7	3.3	2.1	5.7	3.8	2.9	2.1	1.4	2.2	1.8	1.4	1.2	0.9
	13.1	7.3	4.9	3.4	2.1	6.2	4.0	3.0	2.2	1.4	2.5	1.9	1.6	1.3	0.9
	14.0	7.6	5.0	3.5	2.2	6.6	4.2	3.2	2.3	1.5	2.7	2.0	1.7	1.4	1.0
	8.0	5.0	3.6	2.5	1.6	3.3	2.5	2.0	1.5	1.1	1.2	1.0	0.9	0.7	0.6
	9.0	5.6	3.9	2.8	1.7	3.9	2.8	2.2	1.7	1.1	1.4	1.2	1.0	0.9	0.7
	10.0	5.9	4.1	2.9	1.8	4.3	3.0	2.4	1.8	1.2	1.6	1.3	1.2	0.9	0.7
	11.2	6.5	4.4	3.1	2.0	5.1	3.5	2.7	2.0	1.3	1.9	1.6	1.3	1.1	0.8
	12.4	7.0	4.7	3.3	2.1	5.7	3.8	2.9	2.1	1.4	2.2	1.8	1.4	1.2	0.9
	13.1	7.3	4.9	3.4	2.1	6.2	4.0	3.0	2.2	1.4	2.5	1.9	1.6	1.3	0.9
	14.0	7.6	5.0	3.5	2.2	6.6	4.2	3.2	2.3	1.5	2.7	2.0	1.7	1.4	1.0
	15.0	8.0	5.3	3.7	2.3	7.3	4.6	3.4	2.4	1.6	3.0	2.2	1.8	1.5	1.0

spheric transmittance due to air pollution since the transmissivity data in
ssivities are met or exceeded as shown below. Average for all US waters.
met or exceeded 2-3% of the time
met or exceeded 65-70% of the time (T=0.7±0.1 occuring 1/2 of the time)
met or exceeded about 85% of the time
met or exceeded about 92% of the time
met or exceeded about 95% of the time

storage that can physically fit within the LS-59 housing. To do so however, will increase the luminous range by no more than ten percent. The high energy LS-59 should be sufficient to replace almost all of the brightest lights now on buoys. Where brighter lights are needed on minor lights ashore, the LS-59 buoy flashtube beacon will not be a satisfactory replacement.

The ratio of energy levels is 1:2.5:7.5. The effective intensities are similar. Due to Allard's Law, however, the luminous ranges approximately follow 1:1.3:1.8. That is, the ratio of low range to medium range, and of medium range to high range are both about 3/4. The low and high energy are both comparable to the intensities of the dimmest and brightest incandescent lights, and the medium energy flashtube produces approximately the geometric mean intensity. With this in mind, the three energy levels provide good coverage of the range of intensities now in use with incandescent lamps on buoys.

Table 6-3 contains pertinent data on the LS-59 in marine signal lanterns.

6.5 Performance as Buoy Lights.

6.5.1 Lamps - Presently used 12v incandescent marine signal lamps have rated lifetimes of 500 hours. The mortality curves show, however, that there is a large variation in the lives of individual lamps as well as the fact that 500 hours is too large of a figure to use in the real world situation. The effects of shock and vibration on sound buoys, current surges in flashing lamps, as well as a variety of weather and temperature all tend to decrease the lamp life. The use of a six-place lampchanger does increase the expected lifetime of the lighting equipment and decreases the variance of service time until failure, but it is a matter of both providing uninterrupted service as well as pride that requires replacement of lamps before an outage due to failed lamps. The practice has evolved to check the lamps in each aid two to four times a year to relamp the aid before failure of all lamps. From the servicing point of view, this is a costly and time-consuming practice.

It has been pointed out that catastrophic failure of the FX-71 flashtube lamp can be expected to take place long after the efficacy is reduced to 55% of its initial value by the envelope darkening. This value of 55% is referred to since it is the about the value that can be expected from an incandescent lamp (which has lasted a reasonable life) just before catastrophic failure of the filament. Table 5-1 lists the number of flicks which can be expected when this point is reached. Unlike the incandescent case where failure and an outage requiring immediate attention occurs, the flashtube beacon will continue to operate, but at a lower luminous output level. For the typical case of a

TABLE 6-3 Luminous Range for Larger Lanterns

Lantern	Energy Level	Lens/Lamp Ratio	Divergence (50%)	Effective Intensity (a=.21)	Range Dark Background T=.9	=.7	=.5	=.3	=.1	City Background T=.9	=.7	=.5	=.3	=.1
155mm	High	8.4	6.5	290	11.1	6.4	4.4	3.1	2.0	1.9	1.5	1.3	1.1	0.8
	Medium			100	8.0	5.0	3.6	2.6	1.6	1.1	1.0	0.9	0.7	0.6
	Low			40	5.7	3.8	2.8	2.1	1.4	0.7	0.7	0.6	0.5	0.5
250mm	High	8.8	4.1	300	11.3	6.4	4.4	3.1	2.0	1.9	1.5	1.3	1.1	0.8
	Medium			100	8.0	5.0	3.6	2.6	1.6	1.1	1.0	0.9	0.7	0.6
	Low			40	5.7	3.8	2.8	2.1	1.4	0.7	0.7	0.6	0.5	0.5
300mm	High	12.0	3.2	410	12.6	7.0	4.7	3.3	2.1	2.2	1.7	1.5	1.2	0.9
	Medium			140	9.0	5.5	3.7	2.8	1.7	1.4	1.1	1.0	0.8	0.7
	Low			55	6.4	4.2	3.1	2.2	1.5	0.9	0.8	0.7	0.6	0.5

transmissivity of 0.7 per sea mile, a fifty percent reduction in intensity reduces the luminous range by less than 15%. Hence, the replacement of a flashtube beacon due to reduced luminous output is somewhat flexible in scheduling without fear of catastrophic failure or a terribly weak light. Table 6-4 lists the (conservative estimate) effective service life of the LS-59 flashtube lamp as a function of energy level for various characteristics assuming 14 hours per day operation.

It is readily noted from this table that the QkFl(FT)H flashtube beacon is the only characteristic which required servicing of the flashtube lamp more often than once every two years, and that even this worst characteristic does not require normal lamp replacement more than once every sixteen months. This is quite an improvement over checking and relamping every 12v minor aid every 3-6 months, greatly reducing the amount of servicing required by such a lighted aid.

6.5.2 Electronics - Section 5.1.9 discussed the electronic stress analysis made by EG&G, with the results of a pessimistic "worst case" annual reliability summarized in Table 5-5. This resulted in only the complex characteristics having timing circuit reliabilities of less than 0.85, due to the complexity of those circuits. It is of interest to note, of course, that the lack of failures of the electronics on the field and laboratory tests thus far substantiates the pessimism in the analysis. The electronics, in fact, has exceeded the 0.95 annual reliability required of solid-state flashers used with incandescent lamps. The storage capacitors are more prone to failure than the rest of the electronics. There is insufficient data available to determined when these components should be changed as a preventive measure, but certainly no more often than the flashtube lamps.

TABLE 6-4 Flashtube Lamp Life

Characteristic	Effective Lamp Life (months) High	Medium	Low
QkFl(FT)X	16.5	50	132
IQkFl(FT)X	27.5	82.5	220
GPl/3-8.0(FT)X	33	99	265
Fl2.5(FT)X	41.5	126	330
GP2-5.0(FT)X	41.5	126	330

6.5.3 Servicing - Statistics gathered by the Coast Guard's National Navigation Planning Staff have shown that an average 2.4 interim visits per year to 2788 buoys on the Atlantic, Gulf, and Pacific coasts are made for the necessity of checking and replacing lamps in the four-place lampchanger. Another 0.6 visits per year were made to replace batteries. The use of the six-place lampchanger now coming into use should eliminate about one-third of the interim checks, but the total average number of visits per lighted aid will be reduced only from 3.0 to 2.2. On those stations where an LS-59 flashtube beacon could be substituted, not only will the 1.8 interim visits be eliminated, but battery replacement should be only 0.3-0.4 per aid. Since an annual inspection of each buoy will still be required, it should be very rare that an LS-59 equipped buoy be visited more than once a year. Such a reduction in tender time for lighted aids would result in large scale financial savings due to decreased underway time.

6.5.4 Flashtube replacements - When a flashtube beacon is replaced on station due to rated flashtube life limitations, the beacon itself is still reusable. Due to the complexity of the internal electronics, and the presence of potential high voltages (800v) on the storage capacitors, flashtube replacment should not be accomplished in the field. Instead, it will be necessary to set up a repair facility manned by electronics personnel with training in the LS-59. Lamp replacement requires separating the flashtube lamp from the rest of the beacon housing and disconnecting three color coded wires from the lamp to the posts on the top board of the internal electronics. The new lamp is connected and the top resealed. This procedure should take no more than ½ man-hour. It is important that a good seal is made when the new lamp is connected. This was not the case with the flashtube beacon on the Ambrose Channel buoy which was struck. This buoy flooded, and the bad seal on the housing permitted water to enter the beacon, corroding the inside sufficiently to disable the beacon.

Since the storage capacitors are the most susceptable electronic components to fail, it would be a wise preventive maintenance procedure to replace them at the same time as the lamps are changed. This procedure requires separating the upper and lower halves of the housing as well as removal of the lamp. This should require an additional man-hour of time per beacon.

Redesign of the beacon housing to permit easy access to the flashtube and/or storage capacitors is definitely not recommended. Not only would this present high voltages outside the housing, but it would probably increase the chances of failure due to components being open to the atmosphere.

6.6 Fog

The Xenon flash, through its loom, has been reported to be a better

light than an incandescent flash in reduced visibility. The extent of the increased range depends upon the reduced visibility conditions, and no matter how slight, is an improvement. It is not felt that this property is sufficient, under real world conditions which might be encountered, to use such a light as a replacement for sound signals, but the fog penetrating ability would make it a better visual compliment to sound signals than an incandescent flash.

6.7 Color

It has been mentioned above that the LS-59 should not be color coded. The single flick flash length is far too short to expect any degree of correct color recognition, as well as the fact that presently used color lenses produce unacceptable colors when used with the LS-59 source - Transmittance through the red lens is very low, and the color resulting with green lenses does not lie within any definition of signal green. Potentially, color may become an acceptable method of coding with the multi-flick flash, but this will probably require new color filters as well as a lower color temperature flashtube lamp.

6.8 IR Detection

Flashtubes emit a significant amount of infrared radiation. Under another work unit, the Coast Guard is investigating the feasibility for an "infra-red hand gun" detector for use with condenser-discharge beacons. Such a detector uses an extremely sensitive IR photodetector, and many are on the market. If any are sensitive enough, it should be possible to detect a flashtube source on a Navaid with an IR detector before the light is sighted visually.

6.9 Sequential Operation

The Coast Guard now is having a "channel lighted buoy model" constructed. It will be used to investigate the visual advantages and potentialities of sequential and simultaneous presentation of signal lights. It will assist in the assessment of the visual effectiveness of various controlled presentations, and condenser-discharge as well as incandescent characteristics will be evaluated.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 LS-59 Flashtube Beacon

The LS-59 flashtube beacon is a highly reliable and efficient light source. It's use, however, should be restricted because of the nature of the short flash length and high peak intensity which have been found to produce undesirable effects on the mariner. The "flashbulb" effect all but prohibits good fixation, is annoying when seen from close aboard, and can have an adverse effect on dark adaptation (night vision) levels. It appears to be an excellent source to use as a warning light, and has a longer "glow" range in fog than does an incandescent source. It is highly conspicuous when viewed against a complexly lighted background. It should not be used on a station where passing vessels must necessarily pass close aboard, as on channel buoys in restricted waters. They should not be used (on both lights, unsynchronized) on ranges. They should not be used as mass replacement light sources. They should not be color coded.

On the positive side, LS-59's should be used as warning lights on obstructions, on buoy stations where vessels need not pass close aboard, and on many minor lights ashore. Deployment of LS-59's should be made carefully and with advance notice to local mariners. When first introduced into new areas, feedback should be solicitated from the local mariners to assist in determining the number and locations for their use to be most advantageous to the mariner.

7.2 (Multi-flick) Burst Beacons

It is strongly felt that the disadvantages associated with the LS-59 can be eliminated or at least minimized through the use of a multi-flick flash. The LS-59 is a single flick flash source. A reliable and efficient burst source is within the state of the art of flashtubes at present, but no such beacon has been built yet. At the present time, research is being carried out on burst sources, and more will be necessary, before the repetition rate of the flicks, the number of flicks per burst, and the burst flash length can be decided upon which will minimize the "flashbulb" effects while still provided an efficient source. It is possible that this upcoming generation of condenser discharge sources may be efficiently color coded. The burst beacons are not expected to have the limitations placed on their usage that have been found necessary with the LS-59. It will probably be a matter of years until the burst beacons are ready for field use, so the LS-59 should not be withheld from field use pending their availability of burst beacons.

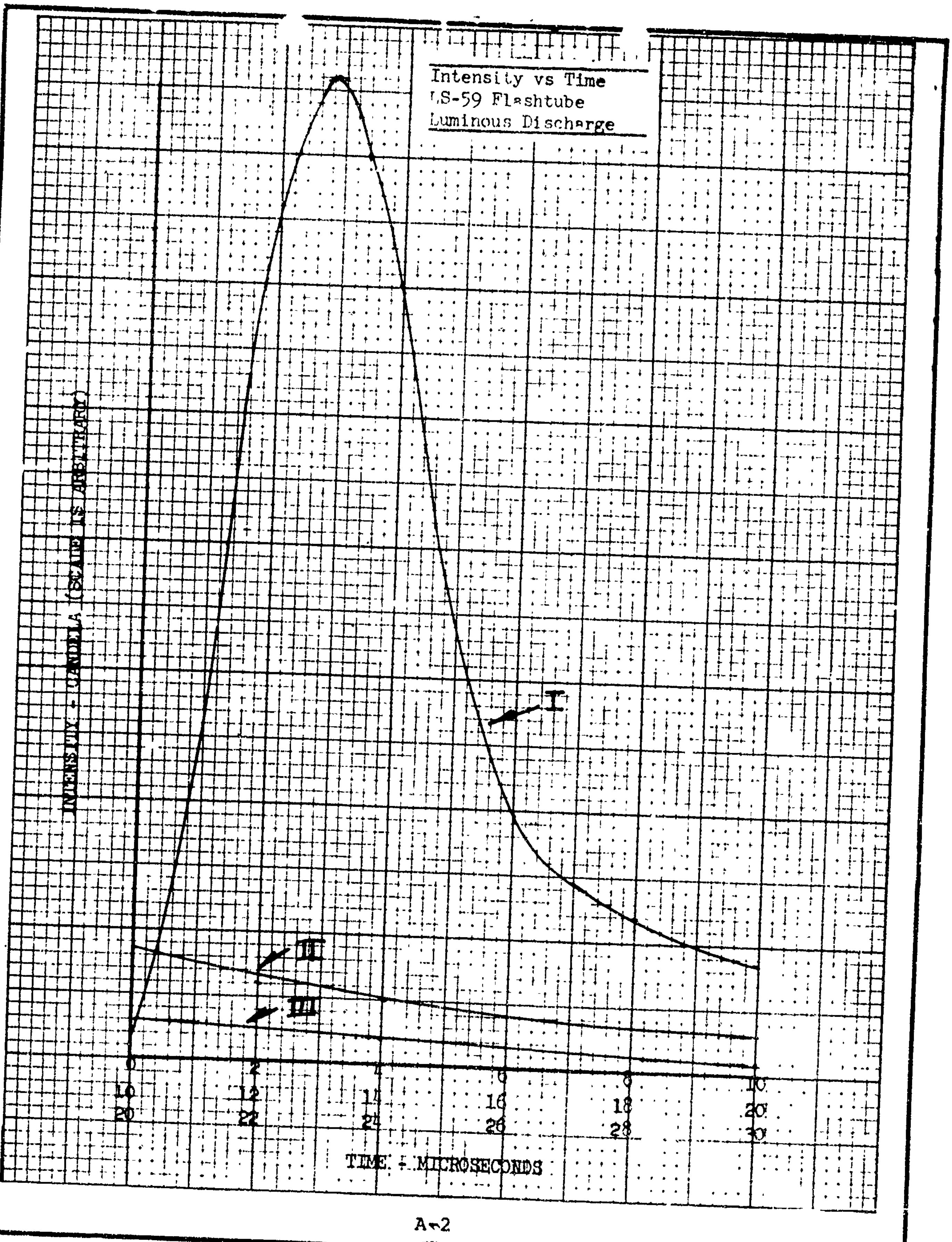
7.3 Need to Continue Development of Condenser-Discharge Sources

The continued development of condenser-discharge sources for use as NAVAID sources is evident. All of the potential advantages can be lumped into a broad category - they are more efficient and more

reliable than incandescent lamps. The greater efficiency extends the servicing period of battery replacement, and this coupled with the better reliability provides an aid which requires far less servicing. Any higher costs of condenser-discharge equipment will more than be saved in the ensuing reduction of the very costly servicing of the aid.

APPENDIX A

TEST DATA



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F T D C SKETCH NO 75-68
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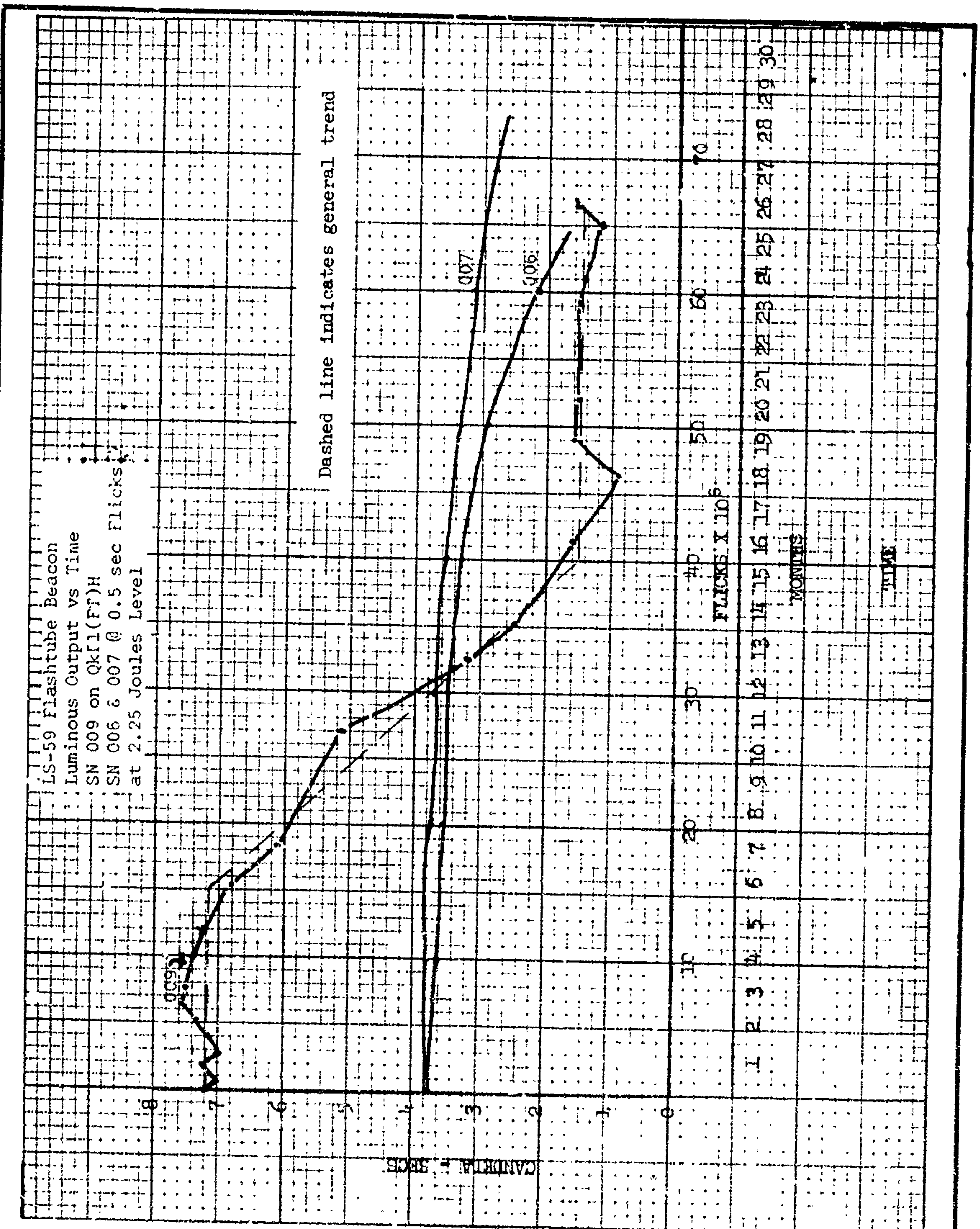

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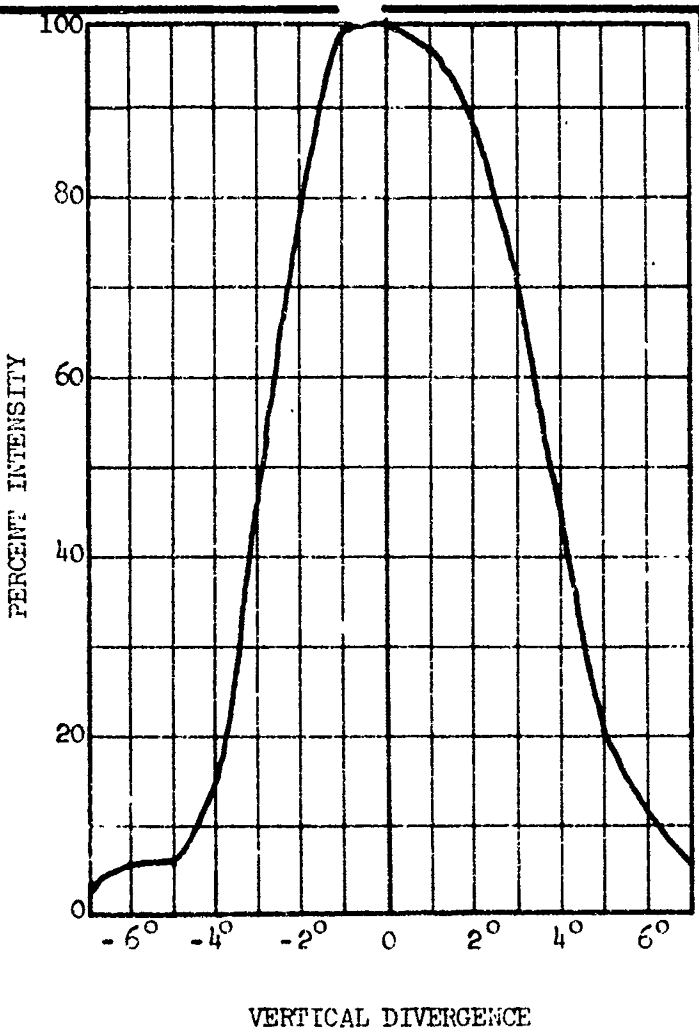

OPTIC DESCRIPTION

155MM Lantern

SOURCE DATA

LS-59 Flashtube S.N. 013	Rated	Tested
Manufacturer	-	EG&G
Voltage	12.0	12.0
Power Input	1.7 watt-sec	2.6 watt-sec
Luminous Output	2.55 cd-sec	3.0 cd-sec
Capacitor	5μf	5μf
Efficacy	1.50	1.15

REMARKS:

Chromaticity co-ordinates:

Color	x	y
White	0.260	0.293
Red	0.659	0.341
Green	0.174	0.308

Optic-source ratio and transmission factors also applicable to high and low power.

Adjusted MHLO (cd-seconds)

	Low Power	Medium Power	High Power
Clear	8.4	21.4	60.5
Red	0.95	2.4	6.8
Green	7.1	18.1	51.1

SOURCE-OPTIC DATA

Optic-source ratio -	
Clear lens	8.40
Red lens	0.95
Green lens	7.10
Transmission factors -	
Red lens	0.11
Green lens	0.84

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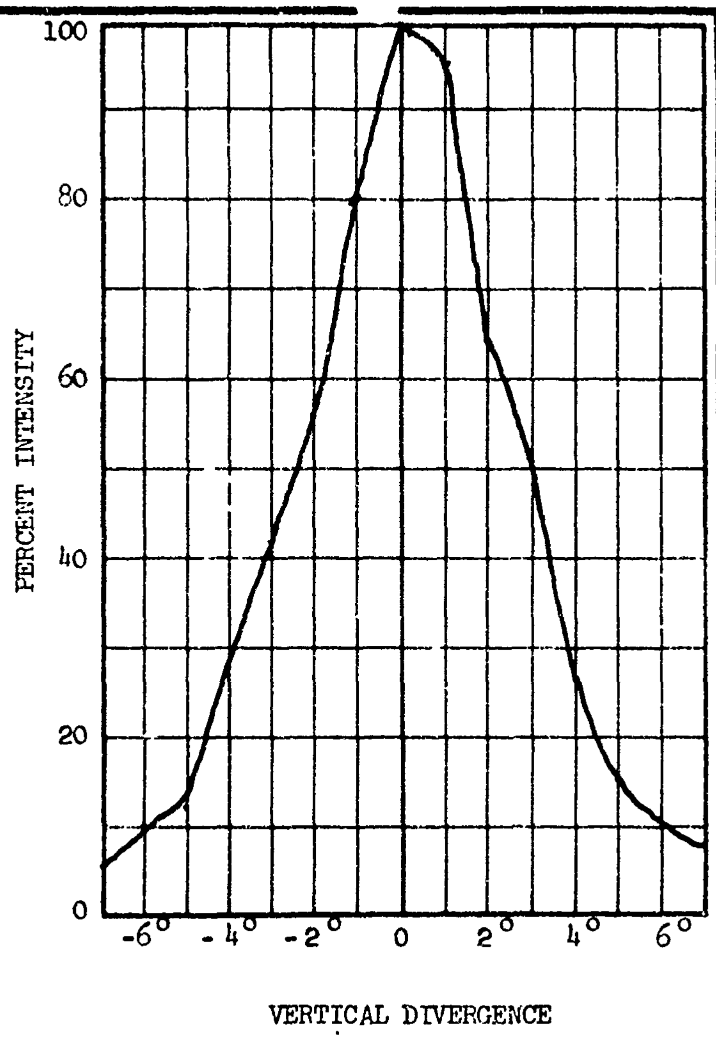

OPTIC DESCRIPTION

200MM Lantern

SOURCE DATA

LS-59 Flashtube S.N. 013	Rated	Tested
Manufacturer	-	EG&G
Voltage	12.0	12.0
Power Input	1.7 watt-sec	2.6 watt-sec
Luminous Output	2.55 cd-sec	3.0 cd-sec
Capacitor	5 μf	5 μf
Efficacy	1.50	1.15

REMARKS:
Chromaticity co-ordinates:

Color	x	y
White	0.273	0.288
Red	0.663	0.336
Green	0.161	0.237

Optic-source ratio and transmission factors also applicable to high and low power.

Adjusted MHLO (cd-seconds)

	Low Power	Medium Power	High Power
Clear	5.30	13.5	38.1
Red	0.32	0.8	2.3
Green	1.84	4.7	13.3

Optic-source ratio and MHLO reduced at Astragals to 94% of values given.

SOURCE-OPTIC DATA

Optic-source ratio -	
Clear lens	5.30
Red lens	0.32
Green lens	1.84
Transmission factors -	
Red lens	0.06
Green lens	0.34

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PHOTOMETRIC SHEET NO. 46-68
DATE 16 October 1968
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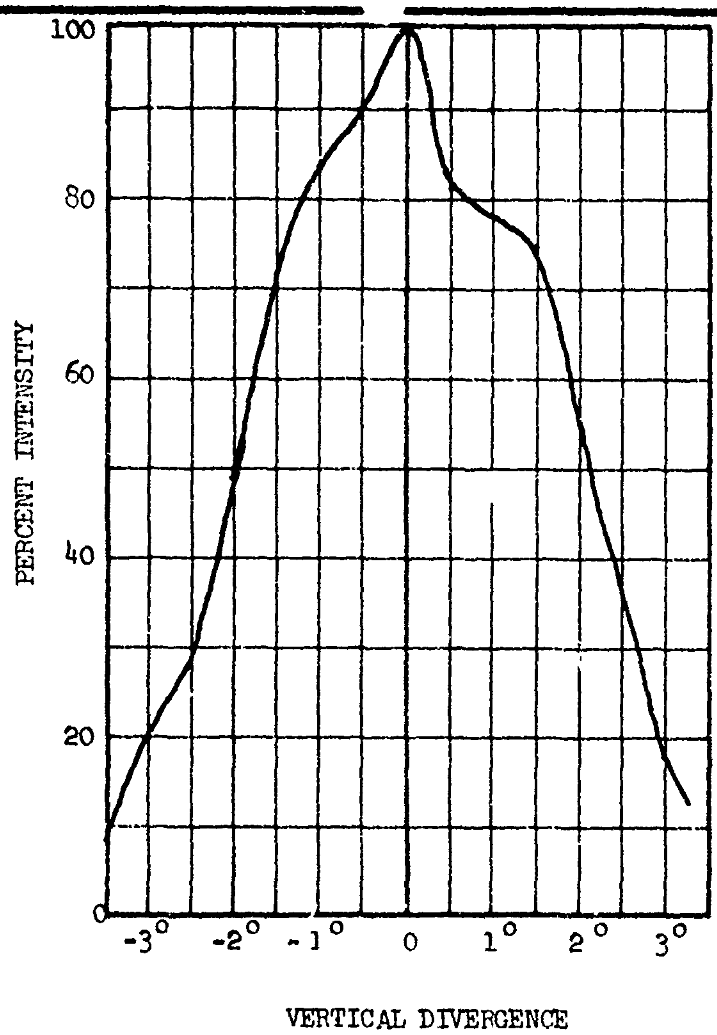

OPTIC DESCRIPTION

250MM Lantern

SOURCE DATA

LS-59 Flashtube S.N. 013	Rated	Tested
Manufacturer	-	EG&G
Voltage	12.0	12.0
Power Input	1.7 watt-sec	2.6 watt-sec
Luminous Output	2.55 cd-sec	3.0 cd-sec
Capacitor	5μf	5μf
Efficacy	1.50	1.15

REMARKS:

Chromaticity co-ordinates:

Color	x	y
White	0.235	0.282
Red	0.666	0.333
Green	0.133	0.136

Optic-source ratio and transmission factors also applicable to high and low power.

Adjusted MHLO (cd-seconds)

	Low Power	Medium Power	High Power
Clear	8.8	22.5	63.3
Red	0.5	1.3	3.6
Green	3.7	9.4	26.7

SOURCE-OPTIC DATA

Optic-source ratio -	
Clear lens	8.80
Red lens	0.50
Green lens	3.70
Transmission factors -	
Red lens	0.06
Green lens	0.42
(Old shade, new green shade not measured)	

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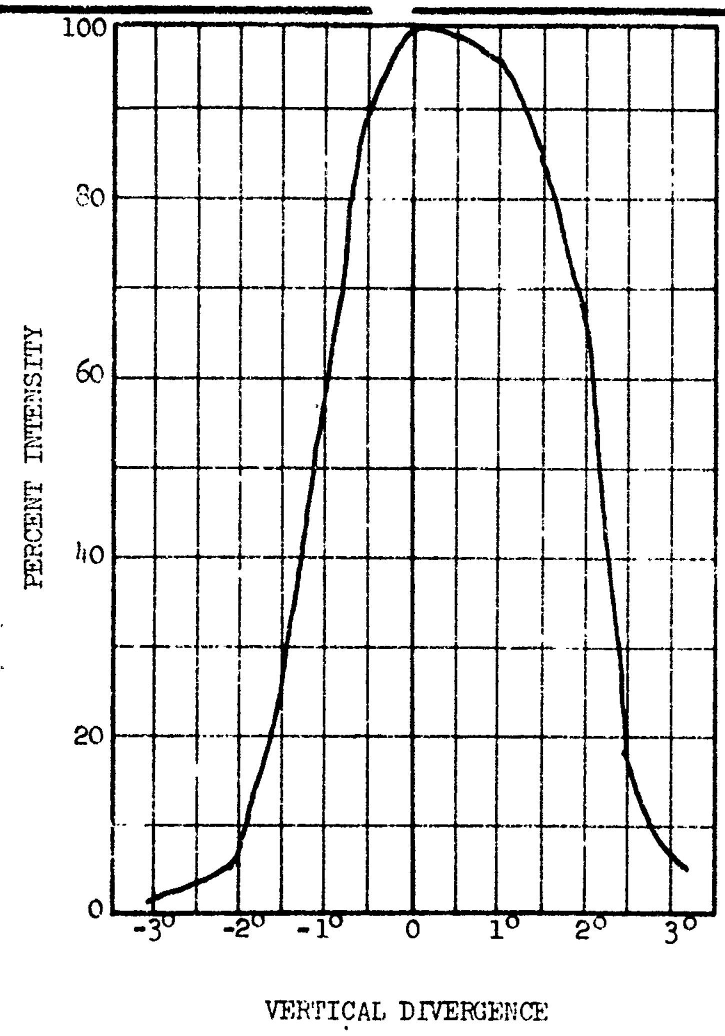

OPTIC DESCRIPTION

300MM Lantern
(Tidelands)

SOURCE DATA

LS-59 Flashtube S.N. 013	Rated	Tested
Manufacturer	-	EG&G
Voltage	12.0	12.0
Power Input	1.7 watt-sec	2.6 watt-sec
Luminous Output	2.55 cd-sec	3.0 cd-sec
Capacitor	5µf	5µf
Efficacy	1.50	1.15

REMARKS:

Chromaticity: x = 0.230

y = 0.259

SOURCE-OPTIC DATA

Optic-source ratio	12.0
Adjusted MHLO -	
Low Power	12cd-sec
Medium Power	30.5 cd-sec
High Power	86.4 cd-sec

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PHOTOMETRIC SHEET NO. 48-68
DATE 17 October 1968
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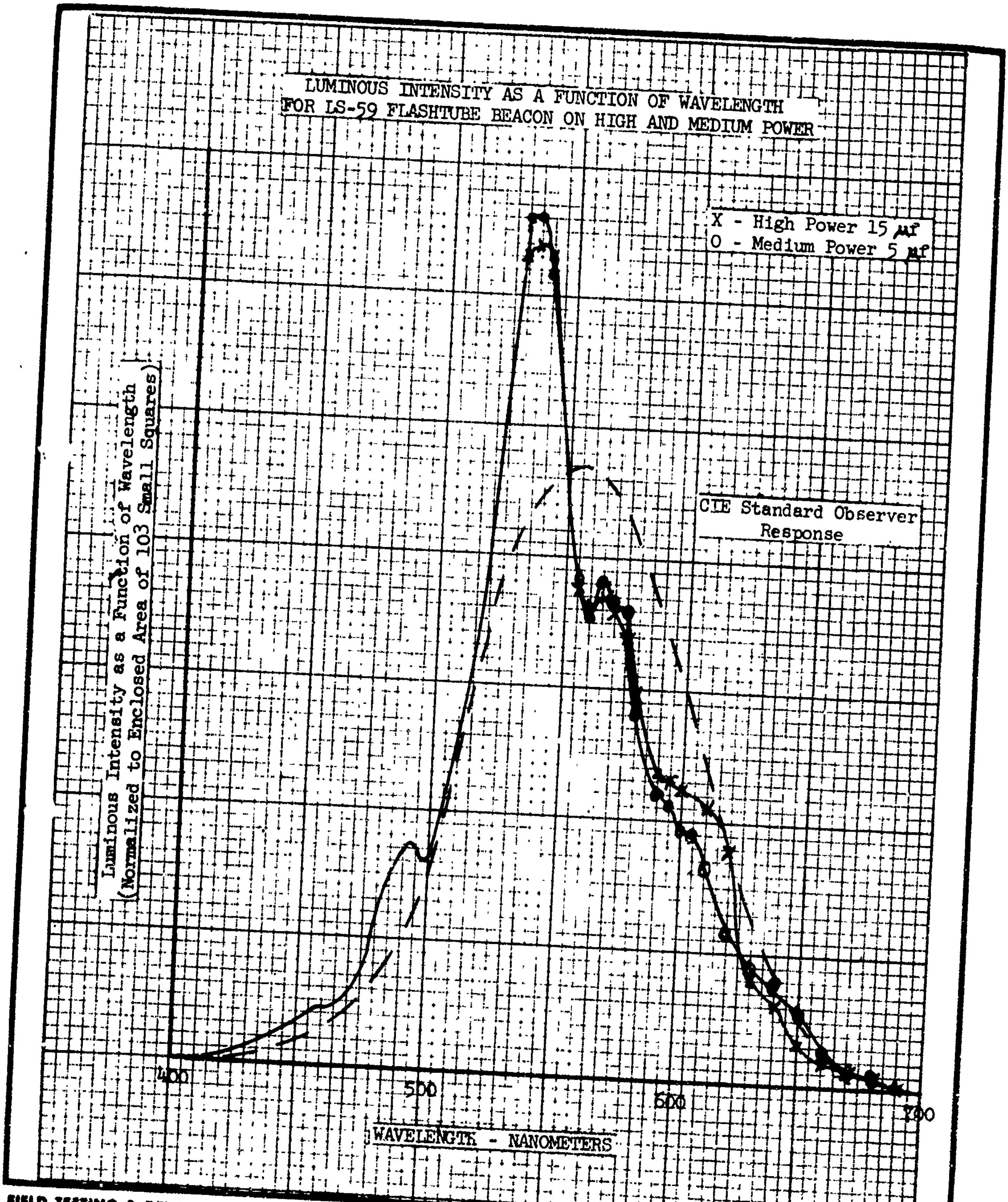

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F T D C SKETCH NO 26-69
DATE 15 August 1969
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APPENDIX B

BUOY FLASHTUBE BEACON SPECIFICATIONS

U.S. COAST GUARD

Applied Technology Division

Office of Research and Development

Proposed Purchase Description

For

12-Volt, Solid-State Flashtube Beacons

For Maritime Aids to Navigation

1. SCOPE

1.1 Scope. This specification covers low power, 12-volt, solid-state xenon flashtube beacons for operation on buoys and fixed structures at 10-18 volts off air-depolarized primary battery or transformer-rectifier DC power supplies. It covers both the electronic and the photometric requirements of the unit. It specifies required minimum luminous output energies for each of three input power levels. It incorporates the concept that beacons which fail after the expiration of warranty for reasons other than defective flashtube lamps will be discarded rather than repaired. In addition, the optional characteristics which must be available for assignment to individual units are stated. The flashtube beacons must be of a reliable design and a rugged construction and be compatible with (i.e., capable of complete containment within) standard 155mm, 250mm, and 300mm lantern assemblies. They must allow easy replacement of flashtube lamps by trained Coast Guard servicing personnel.

1.2 Classification. Flashtube beacons shall be classified by timing characteristic and input energy (per flash) level.

1.2.1 Timing Characteristics. Timing circuits shall provide only the timing characteristic ordered on a particular unit. The minimum time required between flashes is one second. Three types of timing characteristics are required (see 3.1.13): (1) Single-flashing, (2) Group-flashing (3) Composite Group-flashing.

1.2.2 Energy Levels. Flashtube Beacons shall operate at one of three energy levels (see 3.16) designated "L" (low), "M" (medium) and "H" (high).

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of invitation for bids form a part of this specification to the extent specified herein.

SPECIFICATION

MILITARY

MIL-E-16400 Electronic Equipment, Naval Ship and Shore

MIL-P-55110 Printed Wiring Boards

ECV-1 P.D. 190B Purchase Description for Daylight Control For Solid-State Flashers

STANDARDS

MILITARY

MIL-STD-275 Printed Wiring for Electronic Equipment

MIL-STD-454 Standard General Requirements for Electronic Equipment

MIL-STD-202 Test Methods for Electronic and Electrical Components Parts

MIL-HDBK-217A Reliability Stress and Failure Rate Data for Electronic Equipment

MIL-STD-129 Marking for Shipment and Storage

DRAWING AND SUPPLEMENTS (Current Revision)

U. S. Coast Guard

ECV Amerace ESNA 155mm Buoy Lantern

ECV Amerace ESNA 250mm Lantern

ECV Tideland 300mm Lantern

PUBLICATIONS

BUREAU OF SHIPS

NAV SHIPS 94501 Bureau of Ships Reliability Design Handbook

NOTE: Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.

3. REQUIREMENTS

3.1 Definitions. The following definitions shall apply to these terms whenever such terms appear in this specification.

3.1.1 Flashtube Lamp. A gaseous discharge lamp which, when pulsed periodically by a condenser discharge, delivers very short, highly-intense bursts of luminous energy. Within this specification is meant xenon gas discharge lamp.

3.1.2 Flashtube Beacon, Solid State. An electronic device with no moving parts which convert electrical energy into luminous energy. It includes the flashtube lamp.

3.1.3 Flashtube Beacon Assembly, DC- Powered. There is one type of DC-powered beacon assembly on which the flashtube beacons covered by this specification will normally be used. It is described as follows:

Single Lantern. Beacon assembly consisting of a lantern with lens and one flashtube beacon specified herein.

3.1.4 Flick. To provide continuity between this and future specifications, a flick is hereby defined to be the discrete burst of luminous energy produced by a flashtube when it is pulsed by a single discharge from a discharge condenser.

3.1.5 Flash. A flash may contain a single flick or a train of flicks. It is perceived by the eye to have no lapse of light within its duration. In this specification it contains only a single flick; hence, each reference to a flash within this specification shall indicate a "single flick" flash.

3.1.6 Divergence. The vertical angular separation between the intensity halfpower points of a beam of light produced by a source properly focused within an omni-directional lantern, the intensity half power points being the vertical positions at which peak intensity during a flick is half the peak-intensity produced in the focal plane of the properly focused lantern.

3.1.7 Period. The period is the time between the start of one coded sequence of flashes and the start of the next sequence.

3.1.8 Lantern Integrated Intensity. The luminous intensity in the focal plane of a properly focused beacon assembly integrated over time at distances sufficiently great so that the inverse-square law holds; it is expressed in candela-seconds (cd-secs).

3.1.9 Mean Integrated Intensity. Lantern integrated intensity averaged through 360 degrees of horizontal arc, the peak exceeding the minimum by no more than 20%.

3.1.10 Mean Flicks to Failure - MFTF. The expected lifetime of a flashtube in flicks before failure, i.e., before integrated intensity drops below 55% of its original value.

3.1.11 Lens-Lamp Ratio. Lantern integrated intensity in the focal plane of a properly focused flashtube beacon assembly divided by bare lamp integrated intensity in the same direction relative to the lamp but without lantern optic.

3.1.12 Short Circuit. A low resistance path that may be caused by a strand of wire or a metallic tool momentarily connecting terminals or case.

3.1.13 Accessory Functions. There are two accessory functions in the solid-state flashtube beacon covered by this specification. They are defined as follows:

a. Illumination Control. A circuit which, when the proper photoconductive cell (daylight control) is connected to it, prevents the flashtube from flashing if the ambient illumination exceeds a certain value, or, if the illumination falls below a certain other level, permits normal flashing operation (see 3.20).

b. Internal Voltage Regulator. A circuit on the input side of the charging capacitor which regulates the charge of the capacitor over the specified range of open-circuit input voltages and source impedances (see 3.12 and 3.13). This feature is necessary for the stabilization of flashtube life and luminous emittance.

3.1.14 Self-Protection Features. There are two self-protection features in the flashtube beacons covered by this specification:

a. Reverse - Polarity Protection. An electrical circuit that insures that the flashtube beacon will not be impaired in any way if the input terminals are connected across a direct current source in reverse polarity, provided that the source voltage does not exceed the maximum allowable input voltages specified for the beacon.

b. Short-Circuit Protection. An electrical circuit that insures the future functioning of the flashtube beacon to not be harmed if either of the illumination control, "S", terminals is connected to the case, the positive or negative power leads or to each other.

3.1.15 Accelerated Lamp Life Testing Device. A device which triggers a lamp at a rate greater than or equal to ten flashes per second at the energy level required to produce one of the mean integrated intensities specified herein (3.16.2) and which satisfies the power regulation requirements specified herein (3.13).

3.1.16 Encapsulation. The application of a protective coating to a surface by dipping, brushing, or a similar method.

3.1.17 Embedding. The use of a fluid plastic poured over items where all voids between the items are filled. The volume and shape of the embedment are defined by a removable mold that is separated from the solidified casting.

3.1.18 Potting. An embedding process where the mold remains an integral part of the casting.

3.1.19 Impedance-Free Source. An electric power supply with an output voltage variation of 0.5% or less and a recovery time of 50 microseconds or less. A Kepco Model SM regulated power supply is an example.

3.1.20 Timing Characteristics. The sequence with respect to the temporal spacing of the flashes. There are three types:

a. Single Flashing - One flash repeated at intervals of from one to six seconds, e.g., QKF1(FT), F12.5(FT) (see 3.1.21 for designation meanings).

b. Group Flashing - From two to eight flashes per group, with one second between flashes in a group and from three to twelve seconds between groups, e.g., GP2-5.0(FT), IQKF110.0(FT).

c. Composite Group - One flash in the first group with two seconds between the first and second groups; from two to four flashes in the second group with one second between flashes within the group and two to seven seconds between the last flash in the second group and the first flash of the next period e.g., GP1/3-8.0(FT).

3.1.21 Designation. Flashtube beacons are designated according to timing characteristic and energy level. The letters indicate the basic timing character, e.g., Fl, QkFl, IQkFl, and GP. The simple flash character QkFl indicates one flash per second and the simple flash character Fl is followed by a number indica[illegible] the interflash interval in seconds. The group flash character IQkFl indicates six flicks with one second interflick intervals, and is followed by a number equal to the total period in seconds. The group flash character GP is followed by a number equal to the number of flicks with one second interflick intervals, a dash, and a number equal to the total period in seconds. The composite group GP character is followed by the number of flicks with one second interflick intervals in the first group, a slash, the number of flicks with one second interflick intervals in the second group, a dash, and a number equal to the total period in seconds. An (FT) following indicates a single flick flashtube beacon, and an L, M, or H at the end indicates the energy level.

3.2 Qualification. The flashtube beacon furnished under this specification shall be a product that has been tested, and has satisfied the physical and performance requirements specified herein (see 4.2) and that the Contracting Officer, Commandant (FS-1), U.S. Coast Guard, has approved.

3.3 Design Objectives. The design should emphasize the utmost in simplicity and the maximum in reliability, consistent with the state-of-the-art and the limitations specified herein on weight and size. Flash-tube lamps shall be easily replaceable by trained Coast Guard personnel. Since the flashtube beacon will be used as a non-repairable component of a flashtube beacon assembly (3.1.3), its design should emphasize long, trouble-free life, and should make no concessions to maintainability. Solid-state components shall be used to provide static means for accomplishing the flashing function and all accessory functions; in other words, there shall be no moving or adjustable parts.

3.4 Standardization of Design and Certification. Flashtube beacons that are furnished under this specification must not differ in any way from those that have been tested for conformance to this specification except for changes that have been described in detail to and approved by the Contracting Officer. The manufacturer must submit a certification to this effect covering each lot of flashtube beacons furnished under this specification.

In the event the manufacturer wishes to introduce any changes, to correct design deficiencies or selection of marginal parts, etc., the Contracting Officer may require repetition of any or all of the performance tests specified herein before the proposed changes are approved.

3.5 Design and Construction Guides. Maximum use shall be made of NAVSHIPS 94501, MIL-E-16400, MIL-P-55110 and MIL-STD-275 as design and construction guides. In cases of contradiction among them, consult the Contracting Officer for approved guide.

3.6 Failure Rate. The in-service failure rate of all flashtube beacons excluding flashtube failures shall not exceed 5% per year. Flashtube failure rates shall not exceed those specified (see 3.17.1 and 5.2). A flashtube beacon failure shall be any flashtube beacon which does not perform as required by this specification because of random failures of components other than flashtube lamps, or because of defects in workmanship, materials or design, excepting failures due to clear misuse of the flashtube beacon by the government. See 5. for "warranty provisions."

3.6.1 Inspection of Failed Flashtube Beacons. Each flashtube beacon that fails during the guarantee period (see 5.1) will be returned promptly (within 60 days) to the manufacturer, who shall inspect it to the degree necessary to determine the cause of failure. Periodically, as arranged with the Contracting Officer, the manufacturer will submit a complete list of the flashtube beacons that failed during the period, citing them by serial numbers, characteristic, original delivery date, date of return, and a brief description of the cause of failure for each.

3.6.2 Failures due to faulty Flashtubes. In the event that a defective flashtube lamp is determined by the manufacturer's inspection of paragraph 3.6.1 to have caused failure after the expiration of the warranty on the flashtube lamp, the manufacturer shall replace the defective item and may charge the Coast Guard a fixed price established for the repair by the procurement contract (see 5.2).

3.7 Environment. Unless otherwise specified herein each flashtube beacon shall operate as specified in the following environment conditions:

3.7.1 Ambient Temperature. From -10°F through 140°F.

3.7.2 Humidity. From 0% through 100%, relative humidity.

3.7.3 Salt Air and Salt Water. Each flashtube beacon shall be constructed of materials so as to be resistant to corrosion from continuous exposure to salt air and occasional immersion in salt water, and shall not be harmed by such immersion.

3.7.4 Shock and Vibration. Each flashtube beacon shall be ruggedly constructed to withstand the shock and vibrations incident to service on buoys, and shall be capable of passing the vibration and shock test specified in 4.4.8 and 4.4.9.

3.8 Physical Requirements

3.8.1 Weight. Each flashtube beacon shall not exceed 6 pounds in weight.

3.8.2 Size. The flashtube beacon shall fit with ease, with flashtube focused in Amerace-ESNA 155mm and 250mm lanterns and the Tideland 300mm lantern. The clearance required to swing the upper portion of the 250mm lantern closed with the beacon mounted in it is an additional limitation on the size of the beacon.

3.8.3 Mounting Bars. Each flashtube beacon shall be provided with a set of removable mounting bars that fit the mounting studs in the 155mm, 250mm and 300mm lanterns and that, when attached to the mounting holes on the flashtube beacon, place the center of the flashtube at the focus of the appropriate lantern lens. These mounting bars shall conform to drawings ______________ ______________, and ______________.

3.8.4 Terminals and Terminal Insulators. The "+" and "-" power terminals shall be separated with 9/16" to 5/8" between centers. The illumination control, "S", terminals shall be located conveniently (3/4" apart) on the same horizontal plane as and within a ninety degree horizontal arc of the power terminals; each shall be horizontal so as to allow a standard 65 angle between the direction of the daylight control assemblies. All terminals shall be external 8-32 stainless steel screw terminals enclosed in colored slotted insulators sized to accept two 11/32" wide spade lugs for a No. 8 stud. Terminals shall be either separate or part of a terminal strip and molded of colored dielectric materials in accordance with the color code given in paragraph 3.8.5. With one of the above lugs in place, the top of the terminal screws shall not project above the top of the insulators. Terminal screws should be long enough not to fall out when inserting two of the above lugs.

3.8.5 Terminal Markings. Terminals shall be marked in a permanent fashion by the following symbols and colors to be legible for the life of the flashtube beacon:

Symbol	Meaning	Color
"-"	input terminal for the negative battery lead	White
"+"	input terminal for positive battery lead	Black
"S"	two terminals across which the daylight control is connected	Yellow

3.8.6 Classification Marking. Flashtube beacons shall be marked by timing characteristic and energy level (i.e., L, M, or H) in that order e.g., F12(FT)M, GP2-5(FT)L (see 3.1.21).

3.8.7 Nameplates. Nameplates, legible for the life of the flashtube beacon, shall be permanently affixed to the beacon such that the information on at least one of them can be observed from above when the beacon is properly installed within a 155mm lantern pot. Similarly, one nameplate should be observable near the bottom of the beacon when the beacon is rotated back within the upper portion of a 250mm or a 300mm lantern. The information required on each nameplate is listed below. Other information may be included as desired by the manufacturer. The flashtube classification marking shall be 3/32" or larger in size.

Type of Information	Example
Nomenclature	S-S Flashtube Beacon, Type CG-60
Input Voltages	11-18 Volt DC Input
Classification (3.8.6)	IQkF110.0(FT)M
Manufacturer's Name and address	ABC Marine Equipment Company 25 Dock Street Quay, New Jersey 11234
Manufacturer's Part No.	ABC-54321
Date of Delivery to Coast Guard	Delivered 1/1/69
Warranty Expirations	Warranty Expirations - Beacon: 1/1/71 Lamp: 1/1/71

The "Flashtube Lamp Warranty" shall be the appropriate "catastrophic" failure warranty as stated in 5.2.2.

3.8.8 Serial Number. A serial number, not to exceed seven digits, shall be stamped into the flashtube beacon case.

3.9 Flashtube Beacon Case. The flashtube beacon case housing all the circuitry and components excepting the flashtube shall be rugged, corrosion resistant and watertight. The case shall be sealed in such a manner as to discourage opening by field personnel for any purposes, although be such as to allow flashtube lamp replacement by trained personnel. A watertight (see 4.4.10, 4.4.11, 4.4.12) seal between the beacon case and the flashtube shall be provided to protect the electrical connections between the flashtube and the beacon case for the life of the flashtube beacon; the seal shall be easy to replace by trained Coast Guard personnel when they change flashtube lamps.

3.9.1 Accessibility. The circuitry shall be accessible without damaging the circuitry so that in case of failure the cause can be determined (see 3.6.1, 3.10.2).

3.9.2 Electrical Isolation. The flashtube beacon case shall be insulated so that when it is secured to a metallic mounting bar using metallic screws inserted into the mounting holes, the bar and the screws are electrically isolated from each flashtube beacon terminal.

3.10 Materials. Materials and components shall be of the highest reliability and stability of characteristics to insure the highest reliability and long life of the flashtube beacon.

3.11 Workmanship. Workmanship shall conform to Requirement 9, Workmanship of MIL-STD-454.

3.12 Input Power. The flashtube beacon shall operate from air-depolarized primary batteries and transformer-rectifier 12-volt power supplies which have a ripple of 3% or less. It shall operate as required from primary battery power units for flashtube beacon open circuit input voltages ranging from 10-18 volts DC (see 4.4). In no case shall the average load current during one charging period of the condenser exceed .7, .25 and .12 ampere for high, medium and low energy flashtube beacons, respectively, when the timing characteristics fall within the categories defined in 3.1.13. (The average in this case is determined over the charge period, not the period between flashes.) The average current drain over any 0.2 second interval shall not exceed 0.5, 1,2 amperes, respectively. The air-depolarized battery power unit with the widest ranges of voltage and internal impedances has an internal impedance of .2 ohms above 17 volts and 2.5 ohms below 15 volts; between 17 and 25 volts (open circuit), its internal impedance increases in a uniform manner as the voltage drops.

3.13 Power Regulation. An internal voltage regulator (3.1.13) shall regulate the charge on the discharge condensers so that the energy per flash delivered to the flashtube is within ±10% of the value required to produce the candle-second output ordered when the flashtube is new (i.e., before significant bulb blackening). This tolerance shall hold over all source impedance (see 3.12), temperature (see 3.7.1) and humidity (see 3.7.2) combinations required by this specification for all

open-circuit supply voltages exceeding those indicated below:

Energy Level	Open-Circuit (Volts)
High	14.0
Medium	12.8
Low	12.4

3.14 Timing Tolerances. Periods and required intervals between single flashes within a period shall be accurage to within ±3% for all the combinations of open-circuit voltage, internal source impedance, temperature and relative humidity required by this specification. When the input voltage to the flashtube beacon is 12 volts DC from a source with .3 ohms internal impedance (e.g., impedance-free source (3.1.11) with .3 ohms series resistor) in a 70°±5°F room of any normal ambient humidity, period and required intervals between single flashes in the period shall be accurate to within ±3% or ±.5 seconds, whichever is smaller.

3.15 Timing Characteristics. Each flashtube beacon shall provide one of the timing characteristics included within the definitions of 3.1.26. The following timing characteristics, as indicated by the classification markings (3.8.6), are standard at each of the input power levels:

A. Single-flashing

QKF1 (FT)

F12.5 (FT)

B. Group Flashing

GP2-5.0 (FT)

IQkF110.0 (FT)

C. Complex Flashing

GP1/3-8.0 (FT)

3.16 Energy Levels. Each 12-volt flashtube beacon shall operate on one of the following three energy levels per flash:

HIGH (H)

MEDIUM (M)

LOW (L)

3.16.1 Electrical Input Energy. The following energies per flick supplied by the power unit or power supply to the flashtube beacon shall not be exceeded for the energy levels indicated:

Energy Level	Maximum Input Energy
H	7.2 watt-seconds
M	2.7 watt-seconds
L	1.3 watt-seconds

3.16.2 Luminous Output Energy. The following mean integrated intensities (3.1.9) and divergences (3.1.6) produced by 12-volt flashtube beacons in clear 155mm lanterns shall be exceeded in all horizontal directions for the energy levels indicated when the beacons are new and operated above the open-circuit supply voltages indicated in 3.14 (for 2.8 ohms source internal impedance) or operated at 12.2 volts open-circuit voltage from an impedance free source with .3 ohms series resistance or operated at 12 volts from an impedance free source:

Power Level	Mean Integrated Intensity	Minimum Divergence
H	60 candela-seconds	5
M	20 candela-seconds	5
L	8 candela-seconds	5

3.17 Flashtube Lamps. Wide diameter (i.e., low peak current) straight vertical-arc xenon flashtube lamps with greater than 8mm arc lengths coupled with state-of-the-art solid state control circuitry are capable of meeting all the requirements of 3.16. Helical flashtube lamps with greater conversion efficiencies and lesser lens-to-lamp ratios may give comparable peak luminous energies and greater beam divergence.

3.17.1 Flashtube Lamp Life. For the purpose of this specification, a flashtube lamp failure occurs when the mean integrated intensity (candela-seconds) from a 155mm flashtube beacon assembly has dropped below 55% of the appropriate value listed in 3.16.2. The mean flashes (or flicks) to failure (MFTF) listed in the following tables are the minimums acceptable for flashtube lamps at the indicated energy levels - the "months" listed are the corresponding lamp nominal minimum life-times of QKF1 (FT) units operated with daylight controls (14 hours per day operation):

Energy Level	MFTF (Millions)	Months
H	20	12
M	40	26
L	100	66

It is the intent of this specification to maximize flashtube lamp life

in an attempt to minimize the costly logistics involved in lamp replacement.

3.18 Reverse-Polarity Protection. Each flashtube beacon shall have reverse-polarity protection so that connecting the positive and negative leads from an 18-volt DC source respectively to the negative and positive terminals of the flashtube beacon does no harm to the later functioning of the beacon when the leads are properly connected. This reverse-polarity protection shall function at the same time as the short-circuit protection (see 3.19).

3.19 Short-Circuit Protection. Each flashtube beacon shall have built-in electronic short-circuit (see 3.1.12) protection so that connecting either of the "S" terminals to the "+" or "-" terminal does no harm to the beacon; the beacon shall resume functioning as soon as the short circuit is removed without resetting any device. This short-circuit protection shall function at the same time as the reverse-polarity protection.

3.20 Illumination Control. The flashtube beacon shall contain illumination-control circuitry connected internally to the two "S" terminals. A photoconductive cell (daylight control) will normally be connected across the two "S" terminals. The illumination-control circuitry shall function to turn on the flashtube beacon before the resistance across the "S" terminal exceeds 40,000 ohms and to turn off the beacon before this resistance falls below 15,000 ohms. The value of the resistance across the "S" terminals at which the beacon turns on shall exceed the value at which it turns off by at least 5,000 ohms.

If the daylight control is removed from the "S" terminals, all other circuits shall function as specified. The illumination-control circuitry shall not bias the daylight control with more than 6 volts DC. The daylight control, which shall mount directly on the flashtube beacon for use in the interior of the lanter, will be government furnished.

3.20.1 Daylight Controls. When used with the circuit specified in 3.20, a daylight control satisfying the requirements of a "Type C" daylight control in Purchase Description No. 190B shall cause the beacon to turn off before the ambient illumination causes the resistance of the photoconductor to fall below 15,000 ohms. The flashtube beacon shall also be turned on before the ambient illumination causes the resistance of the photoconductive cell to exceed 40,000 ohms.

3.20.2 Prevention of Spurious Activation. Flashtube beacon illumination control circuitry shall not be spuriously activated nor shall the beacon operate on a changed characteristic when light from the flashtube falls on Type C daylight controls while the ambient illumination is less than the level at which the beacon is turned on. This type of spurious activation shall be prevented by "electronic means" and shall not depend upon physical shading of the flashtube lamp.

3.20.3 Effect of Ambient Illumination. The illumination-control circuitry in conjunction with Type C daylight controls shall not cause the flashtube beacon to operate on a changed or partial characteristic at any level of ambient illumination below its "turn-off" level. Spurious

activation in the form of reduced intensity or skipped flicks below the "turn-off" level might be prevented by a positive on/off electronic switching arrangement between the illumination control circuit and the condenser charging circuit.

3.20.4 Daytime Current. The total current drawn by the flashtube beacon under "daytime operation" when the illumination-control circuitry is activated over the range of input voltages specified within this specification shall not exceed 6 milliamperes at $70^{\circ} \pm 5^{\circ}$ nor 25 milliamperes at 140°F.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection. The supplier is responsible for the performance of all production, quality-control inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the government. Inspection records of the examinations and tests shall be kept complete and available to the government as specified in the contract. The government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 Performance Tests. Tests shall be conducted at the manufacturer's plant and/or a laboratory arranged by the manufacturer which is satisfactory to the Contracting Officer. The tests shall consist of all of those specified under 4.3, 4.4, 4.5 and 4.6, except when 4.6 is waived by the Contracting Officer in favor of manufacturer's flash-tube lamp lifetime data (14.6.2).

4.2.1 Test Sequence. The routine tests outlined in paragraph 4.3 may be conducted at the manufacturer's plant by a representative of the Contracting Officer. Samples will not be approved for laboratory and accelerated life testing until they have passed all routine tests.

4.2.2 Sample. Samples submitted for testing shall be representative of the manufacturer's normal or proposed normal production. Samples shall consist of the following characteristics and quantities:

GP2-5(FT)L. . . . . (2)

IQkF110.0(FT)H. . . . (1)

FL2.5(FT)M. . . . . (2)

QKF1(FT)H. . . . . (1)

GP1/3-8.0(FT)H. . . (1)

GP1/3-8.0(FT)L. . . (1)

4.2.3 Acceptance Level. All specimens in the sample must pass the tests in 4.3, 4.4, 4.5 and 4.6 to the satisfaction of the Contracting Officer.

4.3 Routine Tests. Samples from production, or prototypes representative of production, selected as specified by the Contracting Officer in his contract, shall be subjected to the following routine tests at the time of manufacture.

4.3.1 Initial Visual Inspection. Each flashtube beacon shall be visually inspected to see that it meets the following requirements:

A. Terminal labels and markings are properly placed and legible (3.8.5).

B. Terminals are located in the proper location and order (3.8.4).

C. Classification marking on flashtube is correct as specified, permanent and properly placed (3.8.6).

D. Each sample has approved nameplates permanently affixed with all of the required information on them (3.8.7). The serial number does not exceed seven digits and is stamped into the case (3.8.8).

E. Workmanship of exterior of beacon meets the standard required (3.9, 3.11).

F. The vertical dimension of the source exceeds 8 millimeters (3.17).

4.3.2 Mechanical Conformation to Specifications and Drawings. Measure and check the following features for conformation to the specification:

A. Weight (3.8.1).

B. Dimensions (3.8.2).

C. Number, location, depth of screw entrance into mounting holes (3.8.3).

D. Number, thread-type, location and length of terminal screws (3.8.4).

E. Size of slotted terminal insulators and compatibility with two, 11/32" spade lugs (3.8.4) of sufficient height to insulate terminals with one lug in place.

4.3.3 Reverse Polarity and Short-Circuit Protection. Check each flashtube beacon to insure that it meets the requirements of 3.18 and 3.19 by performing the following:

A. With 18-volts reversed input polarity, make the following connections, one at a time, and hold for a complete period on each beacon:

(1) "S", "S", "+", & "-" to a metallic part of the case (if external).

(2) "S" & "S" to "-".

(3) "S" & "3" to "+".

(4) "S" to "S".

B. With normal 18-volts input polarity, repeat the above (4.3.3.A).

4.3.4 Electrical and Luminous Energy per Flash. Using a government-approved photosensitive detector that has a relative luminous efficiency curve closely approximating that of the International Commission on Illumination (C.I.E.) for a "Standard Observer" and a fast oscilloscope or a government-approved integrating device, check the mean integrated intensity (candela-seconds) of each sample flashtube beacon in a 155-mm lantern for conformance to the requirements of 3.16.2 while operating the beacon with an open-circuit input voltage of 12.2 volts DC from an impedance-free source with .3 ohms series impedance. Concurrently measure the power drain of the beacon, checking conformance to 3.16.1 and the maximum average current requirements of 3.12.

4.3.5 Illumination Control. With the flashtube beacon connected to a nominal 12-volt DC power supply and with a Type C daylight control connected between the two "S" terminals, check to see if the illumination control circuitry will turn the beacon on and off as required. Also, insure that each flashtube will not spuriously activate the illumination-control circuitry or cause the light to flash on a changed characteristic (3.20.2, 3.20.3). Remove the daylight control and measure the resistances required to turn the beacon on and off and compare them to the requirements of 3.20.

4.3.6 Isolation of Beacon Case. Check the flashtube beacon to insure that it meets the electrical isolation requirements of 3.9.2 by placing 18-volts DC between each terminal and a metallic portion of the case if it exists whether internal or external (3.9) for at least 5 seconds and noting the current flow. The resistance shall not be less than 1 megaohm between each terminal and the case.

4.3.7 Acceptance Levels. Acceptance levels for routine tests conducted after qualification shall be specified by the Contracting Officer.

4.4 Laboratory Tests. After passing the routine tests and before laboratory tests are begun, all samples, with the "S" terminals left open, will be conditioned first by subjecting them to three 24-hour cycles of temperature variation consisting of approximately 16 hours at 140° ±2°F and approximately 8 hours at -10° ±5°F. The transitions between temperatures shall be accomplished within the 8-hour period so that the time at the high temperature is approximately 16 hours. During the temperature cycling each beacon shall operate from 15-volt DC impedance-free sources.

Upon completion of the conditioning, one each of the GP2-5(FT)L, IQkF110.0(FT)H, F1 2.5(FT)M and GP1/3-8.0(FT)H beacons will be randomly selected for the laboratory tests (the other four will be used for simultaneous accelerated life tests (see 4.5).

Primary batteries shall be simulated in the laboratory tests by use of a regulated, ripple-free, DC, impedance-free source (3.?.19) with an external capacitor bank of 68,000 microfarads connected between the output leads and with a variable resistor in the positive

lead between the capacitor bank and the flashtube beacon. The source impedances and voltages of 3.12 shall be simulated for the beacons listed in the following table by the indicated combinations of power-supply voltage and series resistance used in conjunction with this impedance-free source and capacitor bank:

Combination	Open-Circuit Voltage	Series Resistance	Beacon Load
I	18.0 volts	.6 ohms	GP2-5(FT)L
II	18.0	.3 ohms	IQkF110.0(FT)H
III	13.2 volts	2.8 ohms	F1 2.5(FT)M
IV	14 volts	2.8 ohms	IQkF110.0(FT)M
V	12 volts	1.3 ohms	GP1/3-8.0(FT)M
VI	11.5 volts	2.8 ohms	GP2-5(FT)L

A transformer rectifier power supply with a 3% ripple shall be simulated in the laboratory tests by the use of a 12-volt, 75-100 AH lead-acid storage battery with a 0.36-volt peak-to-peak, 60-cycle AC impedance-free source connected in series with the negative battery lead. The requirements of transformer-rectifier operation in 3.12 and 3.14 will be checked in the tests with the following combinations:

Combination	Beacon Load
VII	F12.5(FT)M
VIII	GP1/3-8.0(FT)H

Where in the following laboratory tests measurements are required at -10°F, flashtube beacons should be connected to a nominal, 12-volt DC power supply and energized with a 1000-ohm resistor across the "S"

terminals during the time they are brought down to the test temperature.

4.4.1 Repetition of Routine Tests. All routine tests specified in 4.3.3, 4.3.5, 4.3.6 shall be repeated in the laboratory at $70^{\circ} \pm 5^{\circ}F$ and at ambient humidity upon completion of the 24-hour cycling.

4.4.2 Temperature Effects on Power Regulation. After making the measurements indicated below for all combinations except V and VI, compare the results for conformance to 3.13 and 3.16.2. All tests are to be conducted with no external connection between "S" terminals using a government-approved photosensitive detector that has a relative luminous efficiency curve closely approximating that of the C.I.E. for a "standard observer" and fast oscilloscope or government-approved integrating device:

A. Determine lens/lamp ratio for 155mm flashtube beacon assembly (i.e., intensity in one direction with and without lantern lens) with the sample beacon that has the largest vertical source dimension.

B. At $70^{\circ} \pm 5^{\circ}F$, measure the beam divergence produced by the beacon of the smallest vertical source dimension in a 155-mm lantern.

C. With all combinations (except V & VI) at $70^{\circ} \pm 5^{\circ}F$, $140^{\circ}F$ and $-10^{\circ}F$, measure mean integrated intensities produced in each case, multiply result by lens/lamp ratio determined in "A" above, and compare the results with the requirements of 3.16.2.

4.4.3 Temperature Effects on Input Energy, Average Current and Timing Accuracy. After making the measurements indicated below for all combinations at $70^{\circ} \pm 5^{\circ}$, $140^{\circ}F$ and $-10^{\circ}F$ compare the results with

the requirements of 3.16.1, 3.12, and 3.14. All tests are to be conducted with no external connection between the "S" terminals.

A. Measure energy per flash into the flashtube beacon (3.16.1).

B. Measure average current into the flashtube beacon (3.12).

C. Measure timing intervals (3.14).

4.4.4 Daytime Current and Temperature. For all combinations at 70° ± 5° and 140°F and with a 1000-ohm resistor across the "S" terminals, measure the current drawn by the four idling sample flashtube beacons.

4.4.5 Illumination Control.

A. "Turn-on" and "Turn-off" Resistance - At -10°, 70° and 140°F, for each flashtube beacon with power supply/resistance combination II and IV listed in 4.4 and a variable resistor connected across the "S" terminals, gradually increase the resistance from 5,000 ohms, stopping at and noting the value at which the lamp begins flashing. Check to insure that initial flashing is on characteristic (3.20.3). Then gradually reduce the resistance from that value, stopping at and noting the value at which the lamp stops flashing. Ensure that all flashing during this "on" period has been on characteristic. Compare the resistance observations with the requirements of 3.20.

B. Bias-Voltage - At 70° ± 5°F, with power source/resistance combination IV of 4.4, measure the biasing voltage across a 1000 ohm resistor (daytime operation) and a 100K ohm resistor (nighttime operation) and compare the results to the requirements of 3.20.

C. Spurious Activation - At 70° ± 5°F, with power source/resistance combination IV of 4.4, the ambient illumination slightly below

the "turn-off" level, insure that the additional illumination from the flashtube does not cause the flashtube beacon to operate on a changed characteristic with a Type C daylight control (3.20.2). In addition, with the ambient illumination set at slightly below the "turn-on" level, insure that the flashtube's illumination does not turn the beacon off nor cause the beacon to operate on a changed characteristic.

4.4.6 Environmental Tests. The functional measurements described below shall be made on each of the four "laboratory test beacons" after each of the following exposure tests for each beacon:

A. Shock (4.4.8)

B. Vibration (4.4.7)

C. Salt Spray (corrosion) (4.4.9)

D. Immersion (Seal) (4.4.11)

E. Accessibility and availability of circuiting for inspection (4.4.12). For all combinations except V and VI at 70° ± 5°, measure mean integrated intensity (3.13, 3.16.2); then repeat 4.3.3 for the four sample beacons. The results of each post-environmental exposure test shall conform to the indicated requirements for the sample to pass the exposure tests.

4.4.7 Vibration. Flashtube beacons shall be tested in accordance with MIL-STD-202, Method 204, using Test Conditions D with the duration reduced to three cycles (each cycle to be 20 minutes long) and the amplitude up to 10 G's in each of three mutually perpendicular directions. The sample shall be attached to the rigid fixture capable of transmitting

all the vibration conditions. During the vibration cycling, the flashtube beacon shall operate under Combination II open circuit voltage and resistance conditions of 4.4. For the first two cycles, the "S" terminals shall be open. During the final cycle, with a 1000-ohm resistor connected between the "S" terminals, the flashtube beacon shall not operate spuriously when subjected to vibration.

4.4.8 Shock. Flashtube beacons shall be tested in accordance with MIL-STD-202, Method 205 B for both normal flashing and normal daytime (sun-switch) operation. Samples shall be rigidly mounted and subjected to thirty-six shocks each, three in each of the six directions specified for each condition of operation. Daytime conditions shall be simulated in this test with a 1000-ohm resistor connected between sunswitch terminals. The flashtube beacons shall not operate spuriously when subjected to shock.

4.4.9 Salt Spary (Corrosion). Flashtube beacons shall be tested in accordance with MIL-STD-202, using Method 101, in a 5% salt solution with a 48-hour exposure time (test condition B). After exposure, exteriors of samples shall be thoroughly inspected for evidence of extreme susceptibility of corrosion.

4.4.10 Humidity Test. Flashtube beacons shall be subjected to 240-hour humidity cycling tests in accordance with MIL-STD-810, Method 507, Procedure 1. Within one hour of the completion of the ten-day test, perform the required functional measurements of 4.4.6.

4.4.11 Immersion (seal). Flashtube beacons shall be immersed in water until at least four feet of water covers each unit. The unit

shall remain in the water for at least 10 minutes. Within one hour of completion of this test, perform the functional tests of 4.4.6.

4.4.12 Accessibility and Availability of Circuitry for Inspection. Within one hour of the end of the immersion test, check that the opening of the samples does not damage the circuitry or interfere with the proper functioning of the flashtube beacon. Check that potting, or other environmental protection, strips off easily according to the manufacturer's instructions (see 3.10.2) without affecting the circuitry, so that components, wiring, etc., may be inspected for defects, failures and workmanship.

4.4.13 Workmanship. Inspect circuitry for evidence of good solder joints, and all the internals for evidence that the specified standard of workmanship has been adhered to. (3.11)

4.4.14 Materials. Inspect circuitry and internals to ascertain that there are no moving or adjustable parts (3.4)

4.5 Accelerated Life Tests. The following four sample flashtube beacons not used in the laboratory tests shall be subjected to an accelerated life test: (1) F12.5(FT)M, (2) QKF1(FT)H, (3) GP25(FT)L and (4) GP1/3-8.0(FT)L. Before the accelerated testing is begun, the sample beacons must be conditioned as described in Section 4.4. The accelerated life test shall consist of operating the flashtube beacon samples at 140°F ± 2°F and at ambient humidity for 360 hours (15 complete days). The beacons, with a type C daylight control, shall be cycled as follows while operating from an impedance-free source:

A. In a darkened test chamber, increase the input voltage to 15.0 volts DC and operate in this condition for one hour and 15 minutes.

B. Then, decrease input voltage to 10.0 volts DC and operate in this condition for one hour.

C. Then increase input voltage to 12.5 volts DC and operate for 1/2 hour at the end of which time the beacons shall be de-energized for 15 minutes.

D. At the end of the 15 minutes shut-down period, operate at 10.0 volts DC for one hour.

E. Increase input to 15.0 volts DC and operate for one hour, fifteen minutes.

F. Then decrease the input voltage to 12.5 volts DC and operate for a period of 1/2 hour at the end of which the flashtube beacons shall be de-energized for 15 minutes.

G. Re-energize at 12.5 volts DC. From the 120th to the 132nd hour and the 240th to the 252nd hour of the test, the ambient illumination shall be raised in the test chamber to 100 foot-candles to insure that all flashtube beacons are turned off by their photoconductors.

Measure mean integrated intensity (3.13, 3.16.2), energy per flash into the beacon (3.16.1) and timing intervals (3.14) after the conditioning of 4.4 before the accelerated life test and again after the accelerated life tests. Measurements will be made at 70° ± 5°F and for impedance free source voltages of 12 and 15 volts.

4.6 <u>Flashtube Lamp Life Tests</u>. Flashtube lamp life more than doubles when input energy per flash is halved. In view of the MTTF

requirements in 3.17.1, therefore, lamp life tests at the high energy level only are required for qualification-medium and low energy lamp lives will be checked subsequent to qualification. Using the contractor furnished accelerated life testing device, lamp life qualification tests will commence immediately upon receipt of sample lamps - a 90% confidence level for a 20 million MFTF for high energy lamps will have been attained when two flashtube lamps have remained above the 55% integrated intensity failure criterion for twenty-four million flashes each (i.e., 27 days each at ten fps).

4.6.1 Input and Output Energies. Input electrical energy delivered to the flashtube lamp from a beacon discharge condenser during each flash will be measured at the beginning of life testing and immediately after the failure criterion has been reached. Output mean integrated intensities (cd-secs) will be measured regularly throughout the performance of the tests.

4.6.2 Waiver. Waiver of the requirement for satisfactory completion of the flashtube life tests before qualification will occur at the discretion of the contracting officer upon presentation of statistical evidence that shows to the contracting officer's satisfaction that the minimum MFTF's of 3.17.1 can be met by the flashtube lamps involved in the qualification. If after waiver qualification and completion of the life tests described above it is found that the flashtube lamp does not satisfy the requirements of 3.17.1, qualification may be revoked by the contracting officer.

5. WARRANTY PROVISIONS

5.1 Flashtube Beacons

5.1.1 Guarantee. Each flashtube beacon shall be guaranteed against failure from all causes, as defined in paragraph 3.6, for two years from the date of shipment of the last flashtube beacon procured under a single contract. The limiting 5% annual failure rate shall be based on the assumption that all flashtube beacons procured under a single contract were delivered on the date that the last flashtube beacon was delivered. Thus, one year after completion of delivery of all flashtube beacons no fewer than 95% must remain in operation. At the end of two years, no fewer than 90.3% ($.95^2 = .903$) must remain in operation; after three years 85.7% ($.95^3 = .857$); etc. For the purpose of annual failure calculations, only flashtube beacons which have failed, been repaired, and been returned to service will still be considered to be failed flashtube beacons.

5.1.2 Annual Failure Rate Not Exceeding 5%. If a flashtube beacon covered by the guarantee fails within two years of the date of shipment of the last beacon procured under a single contract and is returned to the manufacturer as required by 3.6.1, and if the annual failure rate of those beacons still within the two-year guarantee period is less than 5%, the manufacturer shall repair or replace the failed beacon within 30 days after receipt.

5.1.3 Annual Failure Rate not Exceeding 5%. If the annual failure rate of those flashtube beacons still within the two year guarantee

period is greater than 5%, the failed flashtube beacons will be replaced as indicated above (5.1.2).

5.2 Flashtube Lamps

5.2.1 Guarantee Against Non-Catastrophic Failure. Each flashtube lamp shall be guaranteed against non-catastrophic failure, i.e., against 45% reduction failure as defined in 3.17.1, for the following periods from the date of shipment:

Energy Level	Warranty Period (years)
High	1/2
Medium	1
Low	2

These warranty periods are very conservative for the worst case, i.e., the QKF1(FT) characteristic without daylight control, which produces more flashes per day than any other characteristic.

5.2.2 Guarantee Against Catastrophic Failure. Catastrophic failures are more easily detected in the field than non-catastrophic. Each flashtube lamp shall be guaranteed against catastrophic failure, i.e., complete failure, for the periods from the date of shipment indicated in the following table.

Energy Level	Warranty Period (year)
H	1
M	2
L	2

5.2.3 Limiting Failure Rates. A 5% annual failure rate applies for flashtubes as well as flashtube beacons, but only within the period of lamp warranty following the delivery of a new beacon with flashtube lamp. As with flashtube beacons it is based on the assumption that all flashtube beacons procured under a single contract were delivered on the date that the last flashtube beacon was delivered. Thus, six months after the delivery of a high energy beacon, no more than 2.5% of the high energy beacon flashtube lamps must have failed from non-castrophic failure. Similarly, after a year no more than 5% of the high energy beacon flashtubes must have failed from catastrophic failure, and after two years no more than 90.3% of the medium and low energy flashtubes must have failed from catastrophic failure. Regardless of the failure rate, flashtube lamps determined to have failed within the above warranty periods shall be replaced by the manufacturer within thirty days after receipt of the failed lamp.

6. PREPARATION FOR DELIVERY

6.1 Packaging. Preservation and packaging shall conform to manufacturer's commercial practice.

6.2 Packing. Flashtube beacons shall be packed in accordance with standard commercial practice.

6.3 Marking. Interior and exterior containers shall be marked in accordance with MIL-STD-129. Printed precautions necessary for full protection of the flashtube beacons shall be prominently located as specified in MIL-STD-129.

Prospective Bidders List

Sea Light Engineering
2407 Montgomery St.
Silver Spring, Md. 20910

Prodelin Corporation
Navigaide Division
Hightstown, N.J.
Tel: (609) 448-2800

Rainier Corp
2500 S. Perimeter Rd.
Seattle, Washington
Attn: Robert Florence
Tel: RO. 3-0393

Amglo Corporation
c/o Cabel Associates
451 New Jersey Ave. N.W.
Washington, D. C.
Tel: 783-2219

Berkey Technical Corp.
25-15 50th St.
Woodside (NYC), N.Y. 11377
Tel: (212) 932-4040

Xenon Corporation
10 Wheeler CT.
Watertown, Mass. 02172
Tel: (617) 926-2577

Light Energy Systems, Inc.
1601 Redondo Beach Blvd.
Gardena, Calif. 90247
Tel: (213) 327-6700

Illumination Industries, Inc.
610 Vaqueros
Sunnyvale, Calif.
Tel: (408) 738-2744

Northern Signal Co.
Saukville, Wisconsin 5[illegible]080
Tel: (414) 287-2411

The Guest Corporation
Bloomfield, Conn.

The Matrix Corporation
507 Eighteenth St. South
Arlington, Va. 22202
Tel: (703) OT. 4-6600

ACR Electronics Corp.
551 West 22nd Street
New York, N.Y. 10011
Tel: (212) 675-5520

General Systems Inc.
4238 West 12th St.
Erie, Penn. 16505

Union Carbide Corporation
Carbon Products Division
270 Park Avenue
New York, N.Y. 10017
Attn: Mr. Eugene H. Mu[illegible]

EG&G Inc.
Crosby Drive
Bedford, Mass. 01730
Attn: Mr. Martin Schif[illegible]

Kemlite Laboratories, Inc.
1819 West Grand Ave.
Chicago 22, Illinois
Tel: TA 9-6050

Aquadyne, Inc.
414 Main Street
East Falmouth, Mass. 02536
Tel: (617) 548-7777

Flash Technology Corp. of America
Hollis, N. H. 03049

C-R Development Corp.

Automatic Power Inc.

Symbolic Displays Inc.

Grimes Manufacturing Co.

Stone-Chance LTD

AGA Corp.

APPENDIX C

DAYLIGHT CONTROL

APPENDIX C

BEACON DAYLIGHT CONTROL AND DISSIPATION EFFECTS ON RATED BATTERY DISCHARGE TIME

GENERAL

Reference is constant throughout this appendix to solid state flashers. All points made also apply to flashtube and bursttube beacons. The material contained herein shows the return in battery savings to be achieved through close specification of daylight control and dissipation tolerances in flashtube as well as flasher specifications. The recommended flashtube beacon specifications in Appendix B have been developed accordingly.

This appendix draws the following conclusions:

(1) Beacon illumination control circuitry should turn on the beacon before "Type C" daylight control resistance exceeds 40,000 ohms and turn it off before this resistance falls below 15,000 ohms.

(2) The resistance value at which the beacon turns on should exceed the value at which it turns off by at least 5,000 ohms

(3) The fourteen hour average daily operating time assumption of Commandant's Instruction 10500.23 and ECV-40 accounts for worst case Alaska conditions and actual qualified flashers. At the same time, however, it is overly conservative for the southern districts and causes many battery reliefs to be premature by as much as four or five months.

(4) A thirteen hour average daily operating time assumption will cover worst case conditions (e.g., two winters of long nights and one summer of short nights) for all aids south of 50 degrees North.

(5) Month by month discharge calculations accounting for the effects of latitude can reduce Coast Guard battery procurements significantly.

(6) Cloud cover has only slight effect (e.g., ten days) on power unit lifetime prediction accuracy.

(7) Flasher dissipation assumptions in calculating battery lifetimes coupled with the 14 hour assumption for latitudes less than 50°N cause many power units to be relieved more than six months early.

(8) Dissipation assumptions of 10500.23 and requirements of P.D. 181A should be changed to values no greater than those of flashers already qualified.

Turn-on and Turn-off Illumination Levels

The actual turn-on and turn-off illumination levels of an aid are determined by the sensitivity of the daylight control (D.C.) and by the turn-on and turn-off resistances required of the daylight control by the flasher. Sensitivities vary among photocells. Turn-on and turn-off resistances vary among flashers. Because the turn-on and turn-off illumination levels for each flasher/D.C. combination cannot be measured, prediction of daily operating times must be based upon the highest turn-on and turn-off illumination values possible with the hardware, i.e., on the set of illumination values that for any given cloud or visibility conditions will give the longest period of flashing operation possible with the flasher and daylight control used. These maximum values should be determined from specification sensitivity limits for daylight controls and specification minimum resistance limits for flashers. However, greater accuracy is actually possible using the minimum resistances measured to date in CG-181 flasher qualification tests.

Because a daylight control is not equally sensitive to all wavelengths of solar radiation, turn-on and turn-off illumination levels are not the same at each twilight. They actually vary slightly as a function of the color temperature of the sky directly illuminating the daylight control. Cloud cover is a factor in this regard because it affects sky color temperature. For a buoy, D.C. direction is another factor, because it is continually changing; a buoy's daylight control may see a red western sky one minute near sunset and a blue eastern sky a minute later.

The variation among twilights in turn-on and turn-off illumination levels is slight for daylight controls on the CG-181 flashers in clear acrylic lanterns, however, since the daylight controls are installed with inclinations about 65° above the horizontal. The daylight controls, therefore will more often than not be pointed at the blue sky overhead at the times of turn-on and turn-off illuminations.

For clear 155 mm and 250 mm lanterns, present daylight control specifications call for daylight control resistances of 115 K ± 20% ohms when illuminated with 2 foot candles (ft-c) from a 2854 K color temperature (Illuminant A) source. This requirement, which is based on work performed by LCDR K. D. [illegible] in project 390(0/04/01, assumes the North sky to represent the average daily viewing conditions (i.e., average sky color temperature) of a daylight control at turn-on and turn-off illumination levels. For green and red acrylic lenses, the requirement is 62.5K ohms ± 20% to compensate for the reduced transmission of colored lenses, so as to maintain the same correspondence between the daylight control resistances at which the flasher turns

on and turns off and the ambient illumination levels outside the marine signal lantern. Thus, flasher actuation resistance requirements do not depend upon the color of the acrylic lens.

Upper and Lower Bounds

The flasher Purchase Description 181B, requires turn-on in the evening before D.C. resistance rises to 40K ohms and turn-off in the morning before it drops to 10K ohms. It states neither a upper bound for the turn-off resistance nor a lower bound for the turn-on resistance. But, because it does state an upper bound on turn-on resistance, there is actually an upper bound on the turn-off resistance. Similarly, because it states a lower bound for turn-off resistance, there is also an actual lower bound on turn-on resistance.

The explication of these upper and lower bounds evolves from the simple realization that the turn-off ambient illumination in the morning must be greater than the turn-on ambient illumination at night. Because D.C. resistance is inversely related to illumination level, the daylight control TURN-OFF RESISTANCE of a flasher must always be LESS THAN its TURN-ON RESISTANCE. PD -181B, therefore, by stating a maximum turn-on resistance of 40K ohms indirectly imposes on the turn-off resistance an upper limit somewhere under 40K ohms. Effectively, then, both the turn-on and the turn-off resistances are restricted by PD-181B to the 10-40K ohm range with the added restriction that the turn-off resistance value always be less than the turn-on value. The maximum allowed turn-on and turn-off resistances and illumination levels would therefore appear to be those indicated in Table C-1.

TABLE C-1

Apparent Allowed Daylight Control Ranges

	Turn-on (Eve.)	Turn-off (Morn.)
Resistance	10 - 40Kohm	10 - 40Kohm
Illumination	10c - 270ft-c	10c - 270ft-c

It turns out that the daylight control ranges are not actually as clean as indicated in Table C-1. In addition to the requirement that the turn-on resistance be less than the turn-off resistance for each flasher, a requirement is imposed by PD-181B that requires the turn-on resistance to be significantly less than the turn-off resistance. It comes by way of the requirement to prevent a flasher from operating "on a changed characteristic at any level of ambient illumination below its turn-off level", e.g., so as to prevent flashing operating from alternate starts and stops due to the effects of passing clouds on ambient illumination during twilight. This, of course, imposes separation of the turn-on and turn-off illumination levels and the corresponding resistance values.

The minimum difference between turn-on and turn-off daylight control resistances measured in flasher qualification tests to date has (except for one 0°F measurement) been 5Kohms. At first glance, then we might expect the turn-on range to be 15-40 Kohms and the turn-off range to be 10-35 Kohms. However, qualification tests have actually shown (except for the same 0°F measurement) that these ranges are 20-40 Kohms and 15-24 Kohms among qualified flashers. The advantage of specifying the 5 Kohm minimum difference, a turn-on 20-40 Kohm requirement and a turn-off 15-35 Kohm requirement in the flasher purchase description will become apparent in the next section.

Computation of "Average Day" Operating Times

The times each day that the various levels of illumination occur at given latitudes for each declination of the sun are available from the book, Natural Illumination Charts which was published by the Navy Bureau of Ships in September, 1952. Each chart in the book represents "light conditions during average clear days; clear days being defined as less than seven tenths overcast and with the sun's rays unobstructed to the locality in question". When the sun is obstructed by thin clouds, the book recommends multiplying the illumination values by two before entering the charts. For average cloud conditions obstructing the sun, the illumination values are multiplied by three.

Tables C-2, C-3, and C-4 were prepared to facilitate the attainment of the following three ultimate objectives:

(1) to compare and show how the assumptions of 20-40K turn-on 15-24K turn-off and 20-40K turn-on, 15-35K turn-off daylight control ranges can increase lifetime prediction accuracy over that possible with the limits allowed by PD-181B.

(2) to illustrate the effect of latitude on lifetime especially when lifetime is other than an integral number of years.

(3) to critically evaluate the "fourteen hour per day" assumption of Commandant's Instruction 10500.23 and ECV-40 to compute battery lifetimes.

They list for the thin cloud condition the maximum and minimum monthly and yearly "average day" operating times allowed by PD - 181B actual qualified flashers and a PD - 181 specification if modified as recommended herein. The thin cloud condition, as will be shown, is an average cloud condition that is about half way between the lighter average cloud covers of the southern latitudes and the heavier cloud conditions of the Northwest and Alaska. Monthly operating times in the tables were averaged around the 21st day of the month.

TABLE C-2

Monthly "Average Day" Opera
Allowed by Flasher P.D. 181B Da
Requirements for Acrylic lanterns
Obstructed by Thin Cl

	MAXIMUM AVERAGES Off-270ft-c; On-270ft-c										MI Of
Latitude	20 N		30 N		40 N		50 N		60 N		20 N
January	14h	00M	14	40	15	35	17	00	19	45	12
February	13	30	13	40	14	15	15	10	16	15	12
March	13	00	12	50	13	00	13	15	13	30	11
April	12	20	12	00	11	45	11	25	10	50	11
May	12	00	11	20	10	45	10	00	08	40	10
June	11	40	11	15	10	30	09	30	08	00	10
July	12	00	11	20	10	44	09	50	08	30	10
August	12	20	12	00	11	40	11	15	10	35	11
September	13	00	12	50	13	00	13	15	13	30	11
October	13	20	13	40	14	15	15	05	16	20	12
November	14	00	14	40	15	35	16	55	19	40	12
December	14	10	14	50	15	55	17	35	21	40	12
Yearly Average	12	55	12	55	13	00	13	20	14	00	11
Variation	2	30	3	35	5	25	8	05	13	40	2

TABLE C-2

Monthly "Average Day" Operating Times
Allowed by Flasher P.D. 181B Daylight Control
Requirements for Acrylic lanterns when the Sun is
Obstructed by Thin Clouds

ERAGES -c; On-270ft-c							MINIMUM AVERAGES Off-10ft-c; On-10ft-c									
N	40 N		50 N		60 N		20 N		30 N		40 N		50 N		60 N	
40	15	35	17	00	19	45	12	40	13	20	14	00	15	00	16	30
40	14	15	15	10	16	15	12	10	12	30	12	55	13	20	14	00
50	13	00	13	15	13	30	11	40	11	40	11	40	11	40	11	30
00	11	45	11	25	10	50	11	10	10	45	10	20	09	40	08	40
[illegible]	10	45	10	00	08	40	10	40	10	05	09	15	08	05	06	05
15	10	30	09	30	08	00	10	30	09	50	08	55	07	35	04	45
20	10	44	09	50	08	30	10	40	10	05	09	10	08	00	05	55
00	11	40	11	15	10	35	11	10	10	45	10	15	09	35	08	25
50	13	00	13	15	13	30	11	40	11	40	11	40	11	40	11	30
40	14	15	15	05	16	20	12	10	12	30	12	50	13	20	13	55
40	15	35	16	55	19	40	12	40	13	20	14	00	15	00	16	30
50	15	55	17	35	21	40	12	50	13	30	14	20	15	30	17	25
55	13	00	13	20	14	00	11	39	11	40	11	35	11	30	11	15
35	5	25	8	05	13	40	2	20	3	40	5	25	7	55	12	40

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TABLE C-3
Monthly "Average Day" Operating Times
For Qualified CG-181 Flashers in Acrylic Lan
With Daylight Controls When the Sun is Obstructed b

	MAXIMUM AVERAGES Off-100ft-c; On-56ft-c										MINIMUM AVERA Off-23ft-c;		
Latitude	20 N		30 N		40 N		50 N		60 N		20 N		30
January	13^h	15^M	13	55	14	40	15	50	17	50	12	55	13
February	12	45	13	05	13	30	14	00	14	40	12	22	12
March	12	15	12	15	12	15	12	20	12	25	11	55	11
April	11	40	11	20	11	00	10	30	09	50	11	20	10
May	11	15	10	30	10	00	09	00	07	25	10	50	10
June	11	05	10	20	09	40	08	25	06	35	10	45	09
July	11	10	10	35	09	55	08	50	07	15	10	35	10
August	11	35	11	20	10	50	10	25	09	30	11	22	10
September	12	10	12	15	12	15	12	25	12	20	11	52	11
October	12	40	13	05	13	30	14	00	14	50	12	22	12
November	13	15	13	55	14	40	15	50	17	50	12	55	13
December	13	30	14	05	15	00	16	20	18	55	13	05	13
Yearly Average	12	10	12	15	12	16	12	20	12	30	11	50	11
Variation	2	25	3	45	5	20	7	55	12	20	2	20	3

TABLE C-3

Monthly "Average Day" Operating Times

Qualified CG-181 Flashers in Acrylic Lanterns

ght Controls When the Sun is Obstructed by Thin Clouds

MINIMUM AVERAGES

Off-23ft-c; On-10ft-c

	50 N		60 N		20 N		30 N		40 N		50 N		60 N	
40	15	50	17	50	12	55	13	27	14	10	15	07	16	40
30	14	00	14	40	12	22	12	38	13	05	13	30	14	10
15	12	20	12	25	11	55	11	50	11	50	11	45	11	40
00	10	30	09	50	11	20	10	50	10	30	09	45	08	50
00	09	00	07	25	10	50	10	12	09	26	08	10	06	15
0	08	25	06	35	10	45	09	56	09	05	07	35	05	10
5	08	50	07	15	10	35	10	15	09	20	08	05	06	05
0	10	25	09	30	11	22	10	52	10	25	09	40	08	35
5	12	25	12	20	11	52	11	50	11	50	11	45	11	40
0	14	00	14	50	12	22	12	39	13	00	13	25	14	05
0	15	50	17	50	12	55	13	28	14	10	15	05	16	40
0	16	20	18	55	13	05	13	39	14	30	15	35	17	35
6	12	20	12	30	11	50	11	45	11	40	11	35	11	25
0	7	55	12	20	2	20	3	45	5	25	7	55	12	25

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TABLE C-4
Monthly "Average Day" Operating Times
Corresponding to Recommended Daylight
Control Actuation Resistance Values
for CG-181 Flashers in Acrylic Lanterns
when the Sun is Obstructed by Thin Clouds

	MAXIMUM AVERAGES Off; 100ft-c On; 56ft-c										MINIMUM AVERAGE Off; 12ft-c			
Latitude	20 N		30 N		40 N		50 N		60 N		20 N		30 N	
January	13h	15M	13	55	14	40	15	50	17	50	12	45	13	2
February	12	45	13	05	13	30	14	00	14	40	12	15	12	3
March	12	15	12	15	12	15	12	20	12	25	11	45	11	4
April	11	40	11	20	11	00	10	30	09	50	11	12	10	4
May	11	15	10	30	10	00	9	00	07	25	10	41	10	0
June	11	05	10	20	9	40	8	25	06	35	10	35	09	5
July	11	10	10	35	9	55	8	50	07	15	10	45	10	0
August	11	35	10	20	10	50	10	25	09	30	11	15	10	4
September	12	10	12	15	12	15	12	25	12	20	11	45	11	4
October	12	40	13	05	13	30	14	00	14	50	12	15	12	3
November	13	15	13	50	14	40	15	50	17	50	12	45	13	2
December	13	30	14	04	15	00	16	20	18	55	12	55	13	3
Yearly Average	12	10	12	15	12	16	12	20	12	30	11	42	11	4
Variation	2	25	3	45	5	20	7	55	12	20	2	20	3	4

TABLE C-4
Monthly "Average Day" Operating Times
Corresponding to Recommended Daylight
Control Actuation Resistance Values
for CG-181 Flashers in Acrylic Lanterns
when the Sun is Obstructed by Thin Clouds

t-c					MINIMUM AVERAGES Off; 12ft-c On; 10ft-c									
	50 N		60 N		20 N		30 N		40 N		50 N		60 N	
40	15	50	17	50	12	45	13	22	14	03	15	02	16	33
30	14	00	14	40	12	15	12	34	12	58	13	22	14	03
5	12	20	12	25	11	45	11	45	11	43	11	42	11	33
00	10	30	09	50	11	12	10	48	10	23	09	42	08	43
00	9	00	07	25	10	41	10	08	09	19	08	07	06	07
40	8	25	06	35	10	35	09	52	08	58	07	37	04	47
55	8	50	07	15	10	45	10	08	09	13	08	02	05	57
00	10	25	09	30	11	15	10	47	10	18	09	37	08	27
5	12	25	12	20	11	45	11	45	11	43	11	42	11	30
0	14	00	14	50	12	15	12	34	12	53	13	33	13	57
0	15	50	17	50	12	45	13	22	14	03	15	02	16	32
0	16	20	18	55	12	55	13	33	14	20	15	32	17	27
6	12	20	12	30	11	42	11	42	11	42	11	34	11	15
0	7	55	12	20	2	20	3	41	5	22	7	55	12	40

The illumination levels in Tables C-2, 3, and 4 correspond to the maximum and minimum turn-on and turn-off resistances indicated in Tables C-5 for Commandant (ECV-1) PD - 190C daylight controls. Because the flasher purchase description states no minimum difference between turn-on and turn-off D.C. resistances, negligible differences were assumed in computing the "Flasher PD - 181B" values in Table C-2. This covers the not so likely qualification of flashers that have turn-on and turn-off resistances very close to each other, the illumination control circuitry still preventing false characteristics at twilight. The longest daily operating periods in Tables C-2, 3 and 4 occur for flashers with the highest possible turn-on and turn-off illumination values or lowest possible turn-on and turn-off resistances. Conversely, shortest daily operating periods occur for flashers with the highest possible turn-on and turn-off resistances.

The advantage of the Qualified Flasher's 20-40K (56-10ft-c) and 15-24K (100-23ft-c) ranges over the 10-40K range of 10500.23 is immediately obvious from the average day by year operating times in the "yearly average" row of Tables C-2 and 3. By subtracting the smaller 60 N :yearly average value from the larger" in each table, we see that the variation in yearly average day operating times among qualified flashers is at most sixty-five minutes, whereas among "PD 181B flashers" it can be as much as two hours and forty-five minutes. For all latitudes the range of average day per year operating periods permitted by PD - 181B is always greater than twice that actually occurring among "in-service" CG-181 flasher/photocell combinations.

TABLE C-5
FLASHER/DAYLIGHT CONTROL
Turn-on, Turn-off Maxima and Minima

FLASHER	DAILY PERIOD OF OPERATION	D.C. RESISTANCE (Kohm) TURN-on	D.C. RESISTANCE (Kohm) TURN-off	ILLUMINATION (ft-c) TURN-on	ILLUMINATION (ft-c) TURN-off
QUALIFIED	Longest	20	15	56	100
CG-181's	Shortest	40	24	10	23
PD - 181B	Longest	10	10	270	270
	Shortest	40	40	10	10
RECOMMENDED	Longest	20	15	56	100
OFF: 15-35K ON: 20-40K	Shortest	40	35	10	1[illegible]

Recommended D.C. Resistance Values for P.D.-181

The 24K or upper resistance value measured on qualified flashers is an unnecessary upper limit requirement for P.D. - 181. Instead a 35K or upper limit is probably more reasonable for the latitude in manufacturing tolerances it allows. As shown in the Table C-4, it increases the maximum variation in yearly average day operating times among flashers over that of qualified flashers by only ten minutes (i.e., to seventy-five minutes). Hence it seems appropriate to recommend 15-35 Kohm turn-off and 20-40 Kohm turn-on required resistance ranges for P.D. - 181 in addition to a 5 Kohm minimum difference between the turn-on and turn-off resistance values.

Integral Year Battery Lifetimes

According to the figures in the "yearly average" row of Table C-4 battery lifetime predictions determined for flashers purchased in accordance with the recommended values will always be accurate to within 11% at all latitudes for lifetimes approximating an integral number of years (i.e., assuming equal operating periods for all days in operation). Battery lifetime predictions assuming the limits of PD-181B, on the other hand, can be greater than 20% inaccurate.

Accuracy, of course, depends on the assumption of turn-on and turn-off illumination levels used making the prediction. If middle values for qualified hardware were used, accuracy for integral year predictions could be to within ± 5%.

We see by the decrease in range of average day by year operating times that there is accuracy advantage at the southern latitudes. At 30°N for example, where the range among actual CG-181/photocell combinations is but 30 minutes, the greatest possible lifetime over-assumption due to the 30 minute operating time range is 4%, assuming the maximum average day operating time at 30°N (12.25 hours). Hence, we see advantage in taking latitude into account for integral year lifetime predictions.

Latitude is even of more significance in determining the inaccuracy due to the range of operating times among flasher/D.C. combinations when battery lifetimes vary significantly from an integral number of years. But, it is convenient to discuss first the effect of cloud cover on average day operating times.

Average Cloud Cover for Selected Locations

It is convenient to specify local average cloud cover for a year or a month in terms of the multiplier of the "maximum" turn-on and turn-off illumination values (to give worst case battery lifetime predictions) that is necessary for entry into Natural Illumination Charts. This multiplier can be computed for certain selected cities on the assumptions that: (1) the multiplier three, coupled with Natural Illumination Charts, represents cloud conditions for average cloudy days and (2) that the "average percentages of possible sunshine" listed for selected cities in Statistical Abstract of the United States are correct. The computation for Juneau, for example, where only 30% of the daylight hours during a year are clear, would yield a multiplier of 2.4 for the year, i.e., .7 X 3E max + .3E max = 2.4E max, where E max is either the turn-on maximum illumination level or the turn-off maximum illumination level. For Long Beach the multiplier is 1.5. More conservative figures are possible through selection of multipliers greater than three for average cloud conditions on cloudy days.

Multipliers for months would appear also to have significant influence on the accuracy of operating time predictions in places where seasonal differences in average cloud cover occur and where operating times are other than an integral number of years. For instance, at Detroit in the month of July the multiplier would be 1.6, whereas at the same locality in December it would be 2.4. A less extreme example is in Juneau, where the variation is between 2.6 and 2.2.

Table C-6 lists some of the average multipliers for these and other selected localities. The importance or unimportance of making monthly or even yearly considerations of cloud cover in power unit lifetime calculations will be illustrated later in the Mobile/Juneau example.

Lifetimes Varying Significantly From an Integral No. of Years

The average length of a day in a month for any yearly average cloud cover varies among the months. The variation for the qualified flasher maximum turn-on and turn-off illumination values is (Table C-3) under four hours at 30°N and over twelve hours at 60°N. The significance of these variations, especially for northern latitudes, becomes apparent in power unit lifetime predictions when the predicted lifetimes are other than integral numbers of years, e.g., when operation is over more short summer nights than long winter nights.

TABLE C-6

Average Multiplier Selected Cities

	Aug.	Dec.	Year
Mobile	1.7	1.8	1.8
Juneau	2.4	2.6	2.4
Long Beach	1.3	1.5	1.5
San Francisco	1.7	1.9	1.7
Jacksonville	1.8	1.9	1.8
Miami	1.7	1.7	1.7
Atlanta	1.7	2.0	1.8
Honolulu	1.5	1.8	1.6
Chicago	1.6	2.1	1.9
Louisville	1.7	2.2	1.9
New Orleans	1.7	2.0	1.8
Portland, Me.	1.7	1.9	1.8
Baltimore	1.7	2.0	1.8
Boston	1.7	1.9	1.8
Detroit	1.7	2.4	2.0
Sault St. Marie	1.8	2.5	2.1
Duluth	1.8	2.1	1.9
St. Louis	1.6	2.1	1.8
Atlantic City	1.8	2.0	1.8
Albany	1.8	2.2	1.9
Buffalo	1.6	2.4	1.9
New York	1.7	2.0	1.8
Cincinnatti	1.6	2.2	1.9
Cleveland	1.7	2.4	2.0
Portland, Ore.	1.8	2.6	2.1
Philadelphia	1.8	2.0	1.9
Providence	1.8	1.9	1.9
Memphis	1.4	2.0	1.7
Houston	1.3	1.9	1.7
Norfolk	1.7	1.8	1.3
Seattle	1.9	2.5	2.1
Milwaukee	1.7	2.2	1.9
San Juan	1.7	2.2	1.7

For example, consider two aids, one in Mobile and one in Juneau. A 2500 ampere-hour power unit is installed on each on 5 April to power 2.03 amp, 12-volt lamps flashed by FL 6(1.0) solid state flashers having the current dissipations of 10500.23. Commandant's Instruction 10500.23 lists a 445 day expected life for each; if it had assumed 13 hours operation each day, the expected life of these two power units would have been 483 days operation for each.

But the facts that these installations were made in the Spring and that the load is such that the power units will operate for more short summer nights than long winter nights make both predictions too small. Assuming thin cloud conditions for each installation on each day of operation and qualified flasher "maximum" illumination levels (OFF: 100; ON: 56), the 30°N and 60°N average daily operating time data for each month in Table C-3 can be used to show "minimum" life expectancies of 528 days in Mobile and 550 days in Juneau. Therefore, there is an error of about three months for these installations if 14 hours operation each day is assumed. There is an error of about half that if 13 hours operation each day is assumed. These comparisons are apparent in columns I, IV, and V in Table C-7.

Conversely, if the same installations had to experience more long winter nights than short summer nights, predictions based on 14 hour operation each day would still be conservative, but based on 13 hours they would not. For example, if these two installations had been made on 5 October rather than 5 April, actual minimum operating lives assuming the monthly data of Table C-3 would have been 498 days for Mobile and 465 for Juneau (column I). The 13 hour figure, 483 days, would have been overly optimistic for Juneau.

Even 465 days is an optimistic prediction for this example. Average cloud covers in Juneau, according to Table C-6, dictate average multipliers of 2.4, not 2.0. It turns out (Column I[illegible] in Table C-7) that 460 days is a more reasonable prediction of the minimum operating time in days before complete consumption of available power unit capacity.

Thus, we see the one restriction on an overall assumption of 13 hours operation each day. At Northern latitudes, some installations may run the risk of failure before predicted end of life, especially if the flasher dissipation and turn-on and turn-off illumination maximum values are approached, respectively, by the aids' flasher and flasher/D.C. combination.

It is obvious, therefore, that if power unit lifetime predictions for all aids serviced by the Coast Guard are to be based on one universal assumption of daily operating time, Commandant's Instruction

A

TABLE C-7

LIFETIME PREDICTIONS (DAYS)
FOR MOBILE/JUNEAU EXAMPLE

EXAMPLE	Columns	I		II		ACT
	CLOUD COVER EACH DAY OF POWER UNIT LIFE	THIN CLOUDS (MULTIPLIER(2)		AVERAGE CLOUDS MULTIPLIER:3)		(T
	OPERATING TIME EACH DAY OF POWER UNIT LIFE	—		—		
	PERIOD OF AVERAGE	YEAR	MONTH	YEAR	MONTH	YEA
2 SUMMERS 1 WINTER	MOBILE (30 N)	511	528	506	—	514
	JUNEAU (60 N)	500	550	491	542	495
2 WINTERS 1 SUMMER	MOBILE (30 N)	511	498	506	—	514
	JUNEAU (60 N)	500	465	491	458	495

Note: FL6(1.0) Flasher; 2.03 amp lamp; clear acr
2500AH power unit; Flasher Dissipations of
Flasher maximum turn-on and turn-off illum
Accuracy: ±3 days.

TABLE C-7
LIFETIME PREDICTIONS (DAYS)
FOR MOBILE/JUNEAU EXAMPLE

	I		II		III		IV	V
Y	THIN CLOUDS (MULTIPLIER(2)		AVERAGE CLOUDS MULTIPLIER:3)		ACTUAL CLOUDS (TABLE C-6)		10, 500.23	
IFE	—		—		—		14 HRS	13 HRS
	YEAR	MONTH	YEAR	MONTH	YEAR	MONTH	YEAR	YEAR
	511	528	506	---	514	534	445	483
	500	550	491	542	495	546	445	483
	511	498	506	—	514	501	445	483
	500	465	491	458	495	460	445	483

FL6(1.0) Flasher; 2.03 amp lamp; clear acrylic lantern lens; 2500AH power unit; Flasher Dissipations of 10500.23; Qualified Flasher maximum turn-on and turn-off illumination values.
Accuracy: ±3 days.

10500.23 is about as good as we can expect to do for CG-181 flasher/ photocell combinations. But, it is pointed out, AN ASSUMPTION OF 14 HOURS IS NOT GREAT ENOUGH TO COVER THE LIFETIME PREDICTIONS FOR INSTALLATIONS WITH FLASHERS THAT HAVE TURN-ON AND TURN-OFF RESISTANCES WHICH JUST BARELY MEET (I.E. ON: 250ft-c, OFF: 250ft-c) THE REQUIREMENTS OF P.D. 181A. For such flashers, 15 hours is a more reasonable assumption. A tightening of daylight control resistance ranges in P.D. 181A, therefore, appears to be order to achieve a match between actual worse case operating times and the predicted operating times of 105000.23 and ECV-40.

A question remains. Is the convenience of a single overall tabulation for all aids to navigation worth the waste in energy it necessitates? Should reliefs on Gulf Coast be based upon the extreme conditions of Alaska? In general, as has been pointed out, 10500.23 accounts handsomely for the extreme conditions of Alaska. In the Mobile/Juneau example, 10500.23 predicted 445 days for Juneau. The worst operating condition (two winters and 1 summer) for qualified flasher and photocells was 460 days; so, white 445 days covers the worst case in Juneau, it will cause relief of California and Gulf Coast buoys at least 50 days early even for worst case operating conditions. More usual reliefs at most Southern locations will occur at least 100 days early, especially with present procedure that permits relief 30 days earlier than listed in 10500.23. For installations with higher "amperage-duty cycle products", the errors in prediction are even greater.

Slight Effect of Cloud Cover on Prediction Accuracy

A point worthy of note from Table C-7, is the slight impact of cloud cover on life. Columns I, II, and III list lifetimes for thin, average and actual cloud cover averages at Juneau and Mobile. For the predictions based on yearly average day operative times, the greatest difference among cloud covers was 9 days. Again, this difference would become greater for higher wattage lamps, higher duty cycle characteristics or both. A difference of 15 days between multipliers of 1.5 and 3.0 would for some of these appear to be a reasonable expectation.

Flasher Dissipation Effect on the Accuracy of Power Unit Lifetime Predictions

A secondary but significant limitation on the accuracy of power unit lifetime predictions is flasher dissipation. Because the measurement

of flash, eclipse and idle (day) time dissipations of each flasher placed into service is not possible, maximum dissipations must be assumed for all installations. These maximum dissipations should be based on the dissipation measurements of a few representative flashers. Such measurements for CG-181 solid flashers are currently being accomplished in qualification tests.

Flasher dissipation varies as a function of duty cycle, lamp load, power unit internal impedance, open circuitry voltage, and manufacturer (i.e., circuitry design). Table C-8 illustrates the point. In the table, maximum dissipations for flashers qualified to date in accordance with the requirements of Coast Guard PD-181B are listed. It is obvious that daily dissipation increases with duty cycle, a fact that PD-181B realizes by requiring a maximum (10 + 20 X (duty cycle)) milliampere dissipation during flashing operation. Variation among manufacturers is obvious by the differences in maximum dissipations that occur at each duty cycle.

Lamp load, source impedance, and source open circuit input voltage (OCIV) influence flasher dissipation, essentially, through their effects on the closed circuit input voltage across the flasher's power input terminals. These influences are reflected in the qualification test combinations, which are shown below the Table. The test combinations cover the range of closed circuit input voltages possible with currently approved primary batter power units.

The dissipations assumed by Commandant Instruction 10500.23 are also included in Table C-8. For all but one flasher, the assumption of 10500.23 is at least one-tenth ampere-hour per 70 day greater than the highest maximum dissipation measured for the particular characteristic in qualification tests. For a 1.15 ampere lamp flashed by a FL4(.4) flasher off a 2500 ampere-hour power unit, this amounts to an under-estimation by 10500.23 of 50 days of 14 hour flashing operation. Coupled with an 80 days under-estimation due to an assumption of fourteen rather than thirteen hours operation each day, this 50 days contributes to an overall impression of the magnitude of the under-estimations that can occur with 10500.23. The magnitude of these under-estimations are inversely related to lamp amperage, duty cycle, e.g., for a 2.03 ampere lamp flashed on a .167 duty cycle off a 2500 ampere-hour unit, only a 21-day overall under-estimation results from the over-conservative assumptions of flasher drain and daily operating time by 10500.23 when operation is over an integral number of years.

The one flasher which does not have a 70 day capacity consumption that is at least one-tenth ampere-hour less than the one assumed by 10500.23 is the C-R Development Corporation S-1066 FIX flasher. With the S-1069 (C-R's improved successor to the S-1066) however, flasher capacity consumptions daily are in all cases at least .18 ampere-hours per 70 day less than those assumed by 10500.23.

Flasher capacity consumptions are not as different from those of 10500.23 for 125 days as they are for 70 days. The reason is that 10500.23 makes no allowance for increased idle time dissipations in hot weather. These dissipations can become quite significant in places like the Gulf of Mexico where daytime temperatures inside buoy lanterns have been known to exceed 125°F. In these places, worst case daily capacity consumptions can increase by more than 50% (e.g., S-1069 FL 4(.4) and Hayden IQKFL in Table E-8).

In general, Table C-8 indicates over assumption by 10500.23 of flasher dissipation. It has been shown that these over-assumptions can, in some cases, mean an under-estimation in predicted life of more than 50 days. It is recommended, therefore, that the dissipation assumptions of 10500.23 be lessened to values very close to the maximums measured in qualification tests to date. It is also recommended, that the dissipation requirements of P.D. 181A be tightened. Future qualifiers should be expected to produce flashers with minimum dissipation no greater than those of the flashers already qualified.

TABLE C-8

SOLID STATE FLASHER MAXIMUM DISSIPATIONS

CHARACTERISTIC	DUTY CYCLE	FLASHER	TEST COMBINATION	CURRENT (ma) NIGHT	CURRENT (ma) 70 DAY	CURRENT (ma) 125 DAY	AMP-HRS 14 hr DAY 70 DAY	AMP-HRS 14 hr DAY 125 DAY
FL 4 (.4)		VAP-AIR	II	6.12	1.1	2.3	.10	.11
		S-1066	I	7.2	5.5	11.8	.16	.22
	.1	S-1069	IV	4.4	3.0	8.0	.09	.14
		HAYDEN	I	8.6	4.9	10.1	.17	.22
		10,500.23		13.5	10	10	.29	.29
IQK FL (6 x .3)	.18	VAP-AIR	II	12.3	1.1	2.5	.18	.20
		S-1066	I	10.7	5.8	12.3	.21	.27
	.18	S-1069	IV	7.3	4.4	11.0	.15	.22
		HAYDEN	I	11.3	4.7	15.7	.21	.32
		10,500.23		16.3	10	10	.33	.33
QKFL (0.3)		VAP-AIR	I	7.9	1.2	2.6	.12	.14
	.3	S-1066	IV	10.4	3.8	8.9	.18	.24
		HAYDEN	VI	12.8	4.2	12.4	.22	.34
		10,500.23		20.5	10	10	.39	.39
MO(A) (0.4, 2.0)		VAP-AIR	I	8.9	1.2	2.5	.14	.15
		S-1066	I	10.4	5.6	14.4	.20	.29
	.3	S-1069	IV	7.8	3.4	6.1	.14	.17
		HAYDEN	VI	14.2	5.2	12.0	.25	.32
		10,500.23		20.5	10	10	.39	.39
EINT 6 (3.0)		VAP-AIR	I	9.8	1.2	3.0	.15	.17
		S-1066	IV	14.2	5.0	7.2	.25	.27
	.5	S-1069						
		HAYDEN	VI	16.3	4.5	12.7	.27	.36
		10,500.23		27.5	10	10	.49	.49
FIX		VAP-AIR	IV	20.7	1.65	2.32	.31	.31
		S-1066	V	43.2	4.7	10.3	.65	.71
	1.0	S-1069	V	20.0	3.5	11.0	.32	.39
		HAYDEN	VI	31.3	3.3	7.9	.23	.28
		10,500.23		45	10	10	.65	.65

Test Combination Key:

Combination	OCIV(volts)	Source Internal Resistance(ohms)	Lamp Load(amps)	Typical CCIV(volts)
I	18.0	.6	.55	17.5
II	18.0	.3	3.05	17
III	13.2	1.2	.55	12.5
IV	13.7	.4	3.05	12
V	11.5	2.8	.55	11
VI	12.4	.8	3.05	10.5

APPENDIX D

VISION THEORIES

General

The means of determining the useful visual range of a marine signal light is Allard's Law: $E_t = \frac{I_e T^D}{D^2}$,

where:

E_t is a minimum threshold of illumination at the eye required to stimulate a response from the visual system (for a fixed light)

I_e is the effective intensity of the signal light computed from the Blondel-Rey relationship

T is the atmospheric transmissivity, and

D is the distance from the signal light to the observer.

For a steady light, the effective intensity is the fixed intensity of the light. The threshold illumination generally used in Allard's Law, 0.2 microlux, is well above laboratory threshold and has been chosen to cover the shift of conditions from the laboratory to the real world. In 1911, Blondel and Rey found a relationship to equate the threshold of flashing "square" shaped pulses to fixed intensities. For any square flash, they found that the intensity required was that which increased the fixed light threshold by a factor of a/t. That is, $I = E_t \frac{(a+t)}{t} \frac{D^2}{T^D}$. Since the time and the intensity dependence are both functions of the light source, it is most convenient to lump them together, yielding an effective intensity for the flashing light which can be used with the fixed light threshold illumination. Thus, $I_e = \frac{I \cdot t}{a+t}$. The value they found in their free search situation for a was 0.21 seconds. This is the intersection of the two asymptotes of the relationship, I = constant for long flashes, and Bloch's law, $I \cdot t$ = constant for short flashes. It was then postulated that for other than square flashes, I_e could be defined by $\frac{\int I dt}{a+t}$. This is the general Blondel-Rey relationship, although the integration limits were still undefined. Douglas elegantly showed that a unique solution could be found, which is the maximum value, by using the times when $I = I_e$ as the integration limits. Schmidt-Clausen has shown that the Douglas solution fails for flash lengths near the critical duration, a, and finds instead a form factor equal to the ratio of the integrated area of the flash divided by the area of a square flash of the same I_{peak} and time duration to be used with the latter square flash. It is only near the critical time duration that these variations occur. Both methods yield the steady state I for long flashes, and the total integrated intensity at very short flash lengths.

Integration Limits and Effective Intensity

For the LS-59 flash, with a duration of tens of microseconds, any Δt which is chosen is negligible compared to a, and $I_e = \frac{\int Idt}{a+t} = 4.76 \int Idt$, where the intensity is integrated over the entire flash. Even if the Douglas approach is used, (referring to the flash shape in Appendix A) $I_{peak} \gg I_e$, and any difference is negligible For the LS-59, $I_e = 4.76 \int Idt$.

The "Variable Constant a"

The literature shows that values of a have been found which vary from less than 0.1 to more than 0.35. Under a given set of conditions, however, a is found to be constant. But, a varies with the conditions under which the test is performed. Two general trends can be noted regarding the change of a with changing conditions. First, a is generally found to be larger when threshold data is being collected than when supra-threshold brightness matches are made. Second, if a free search procedure is used, a is generally greater than 0.2, while in cases of forced fixation a is found to be about 0.1 and the data follow the asymptotes into a.

In the real world marine environment situation there are generally no fixation lights available to maintain forced fixation. Thus, the general case requires the free search data. For the few cases where it is known exactly where to look for a light, the free search curve leaves a margin of safety in further calculations. Use of the forced fixation data in a free search situation will of necessity overrate the light. The only reasonable approach is to use the free search data. Effective Intensity is put to an end use in Allard's law to find the range at which a light can be detected. I_e is, therefore, a quality of a light at or near its detection threshold. Even Blondel and Rey noted in their report over a half-century ago that two lights of different flash lengths which disappear at the same range (equal effective intensity) do not appear equally bright when viewed at higher supra-threshold levels. The light with the shorter flash length always appears brighter than the one with the shorter flash length at these higher levels. This is explained by a decrease in a when viewed at supra-threshold levels. This smaller a has been shown by many investigators. Since I_e is a threshold descriptor, its value should be based on threshold data. Supra-threshold apparent brightness may require a similar descriptor of its own, but is not pertinant to the threshold situation.

It is this lowering of a with increasing illumination which at least partially explains the "flashbulb" effect. The reason for this change

is not known, but can at least be attributable to changes in the processing in the visual system (retinal photo-chemical processes) caused by a change in the viewing conditions. The apparent brightness of the LS-59 flick when viewed from close aboard could be bright enough compared to the adaptation level of the visual system so as to appear as a glare source.

Effects of Retinal Location of Detection

In a dark adapted eye the focal point is less sensitive than the surrounding areas. This is equivalent to saying that the focal point has a higher threshold. The threshold continually falls off in all directions for about 5^{o}. With the precise fovial centralis forced fixation, the higher threshold will require a higher illumination to produce the threshold sensation than for some portion of the surrounding fovea-near periphery where a free search situation would have the light fall. For the fixed light asymptote, there should be a decrease in the threshold illumination needed proportional to the change in sensitivity. The Bloch's law region is probably somewhat different. This region, essentially being a photon counter, would be more susceptible to variations in the number of photons within a given flash than the fixed light asymptote which acts more as an averager of larger numbers of photons. Considering that the standard deviation of the number of photons per short flash varies as the square root of that number, it is not too surprising that Kishto has data showing that the fixed light asymptote threshold decreases more rapidly than the Bloch's law asymptote as the flash is moved from a less sensitive to a more sensitive portion of the retina. The Bloch's law region threshold seems to have a dependence on the standard deviation of the number of photons needed.

In the free search situation, where a more sensitive portion of the retina is apt to be used (than in forced fixation), the effect of the Bloch's law asymptote lowering by a lesser amount than the fixed light asymptote results in an increase in the time of their intersection, that is, a.

Apparent Brightness and Probability of Seeing

Blackwell and McCready have found that detection probabilities near fifty percent threshold are dependent upon flash duration, target size, and background luminance. Their data, for flashes with rise and decay in the flash of 10^{-4} seconds, yielded an average σ/M of 0.390, but varied with conditions. Scaling their data to the σ/M of the 1' target and 10^{-3} ft-L background illumination, we can calculate

flash duration	1 sec	1	1/3	.1	1/30	$\leq$ .001
σ/M	.5	.493	.458	.380	.378	.357

In order to adjust from a fifty percent probability of seeing to some higher probability, the number of standard deviations needed to reach that probability will depend upon the size of the standard deviation for the particular flash length. Thus, near threshold, an 84% threshold ($+1\sigma$) would require $1+\sigma$ times the fifty percent threshold value, which would vary as σ varies. A 95% probability threshold ($+2\sigma$) requires $1+2\sigma$ times the fifty percent threshold values.

Thus, if we have two lights of different flash lengths equated at fifty percent threshold, at closer distances from the lights the same integrated illumination requires a greater number of σ from the light with the smaller σ than from the light with the larger σ. Since σ is smaller for shorter flash lengths, a short flash well above threshold is seen with a higher probability (more σ) than a long flash of the same fifty percent threshold. Although both essentially could have 100% probability of seeing at plus several σ, the number of σ above fifty percent could be postulated as indicative of the apparent brightness.

Take two lights at the extremes of the asymptotes, that is a fixed light and one with a flash length of 10^{-6} seconds, and consider a brightness match several orders of magnitude above threshold. In this case, $n\,\sigma/M$ and $m\,\sigma/M$ are both much greater than 1, so that $\frac{(1+n(\sigma/M_1))}{(1+m(\sigma/M_2))} \approx \frac{n(\sigma/M_1)}{m(\sigma/M_2)} = \frac{.357n}{.5\ m} = .714\frac{n}{m}$. For this equal apparent brightness, then, we need to raise the Bloch's law asymptote only .714 times this distance as the fixed light asymptote. This can be considered to change a, the intersection of the two, also by a factor of .714. Taking $a = 0.21$ at threshold, at this high brightness match, the critical duration is $0.714 \times 0.21 = 0.15$. This is the value recently postulated by Naus doing brightness matches. If we find this relative equivalence for all the t's listed by Blackwell and McCready in addition to the two end points where $t \gg a$ and $a \ll t$, we are redefining a

as $\hat{a} = \frac{\sigma/M_t}{\sigma/M_f} \times (0.21 + t) - t$, yielding

t	Fixed	1 sec	1/3	.1	1/30	.01	.01
$\hat{a}$	0.21	0.19	0.16	0.135	0.15	0.15	0.15

The value of a for the fixed light is insignificant compared to an infinite t, but the different values (than 0.15) above 1/30 sec. show that a is not constant throughout all t for this supra-threshold brightness match. The variation shown for a gives variations from the Blondel-Rey shape which seem to relate to Broca-Sulzer effect.

This approach of linking threshold to supra-threshold brightness is essentially a summary of a more rigorous approach now being prepared for presentation. It presents the results of such an approach which attempts to link these two different visual tasks.

"Flashbulb" Effect

The "flashbulb" effect is at least partially explained by the two preceding sections. The apparent brightness of the flashtube when viewed from close aboard is greater than that of an incandescent flash of longer duration of the same effective (threshold) intensity. Additionally, the incandescent flash is sufficiently long to allow direct fixation in the least sensitive retinal area while the flashtube flick is so short that it almost always falls, in its entirety, in a more sensitive area. The dark adapted eye may also find that the peak illumination in the flashtube flick, when close aboard, is sufficient to be considered a glare source.

"Glow Range" in Fog, and Scotopic Vision

The xenon flashtube light is much bluer than the incandescent light, and has a color temperature of approximately 15,000°K. Long (1951) has shown that in the Block's Law region, $t \lesssim 0.1$ sec there is no dependence on $\frac{dI}{dt}$ for the detection of light flashes. We should therefore assume that the greater rate of temporal contrast for the flashtube does not carry over into the visual effectiveness.

Measurements of intensity are made in candela, and inherently account for the spectral distribution of the light within the sensitivity curve of the 1931 CIE Standard Observer.

For normal viewing of point sources, a 15,000°K flashtube flick of 100cd-sec yields 476cd for an effective intensity. This same I_e can be attained from a 0.3 second incandescent flash (2850°K) of 809 candela. These two lights will be equally effective at a detection range determined by Allard's Law with regard to some probability of seeing for the purpose of taking bearings.

When a subthreshold situation is viewed, the flashes will not be seen fovially. However, the peripheral sensitivity, when dark adapted, is 1-3 orders of magnitude greater, and will give rise to peripheral detection when below foveal threshold. The sensitivity curve of the periphery differs appreciably from the fovial sensitivity curve. The major difference is a peak at 507nm peripherally rather than 555nm foveally. Under this scotopic viewing, the equal effective intensities

for our two lights again becomes inapplicable, but now because the sources have different spectral emissions.

In the photopic case, $I = K\int V_\lambda W_\lambda \, d\lambda$ where W_λ is the power distribution, $\int I_{FT} dt = 100$ cd-sec and $\int I_{INC} dt = 809 \times .3 = 243$ cd-sec

yielded the same $I_e = 476$ cd.

In the scotopic case, $I' = K' \int V'_\lambda \, W_\lambda \, d\lambda$.

In the "Purkinje shift" from photopic to scotopic vision, $\frac{I}{I'} = \frac{K \int V_\lambda \, W_\lambda \, d\lambda}{K' \int V'_\lambda \, W'_\lambda \, d\lambda}$, and for the same light, $I = I'$, and $\frac{K'}{K} = \frac{\int V_\lambda W_\lambda d\lambda}{\int V'_\lambda W_\lambda d\lambda}$

Utilizing, for simplicity, black body radiation curves, and performing the indicated integrations, we find:

Color Temperature	K'/K
1600°K	3.33
1800°K	2.78
1900°K	2.57
2000°K	2.40
2100°K	2.25
2200°K	2.12
2300°K	2.01
2350°K	1.96
2365°K	1.95
2600°K	1.79
2850°K (Ill A)	1.60
3000°K	1.53
3200°K	1.44
4000°K	1.20
5000°K (Ill B)	1.06
Equal Energy	1.00
6000°K	0.98
6500°K (Ill D)	0.92
7000°K	0.91
Ill C	0.90
10,000°K	0.81
15,000°K	0.74
20,000°K	0.71
40,000°K	0.68
	0.65

We can immediately note that for the 2850°K incandescent light, $K'_{INC}/K = 1.60$ and for the 15,000°K flashtube, $K'_{FT}/K = 0.74$.

Thus, in the shift from photopic to scotopic (or foveal to peripheral) vision for our two lights of equal photopic effective intensity, ($I_{INC} = K \int V_\lambda W_{\lambda\, INC} d\lambda = I_{FT} = K \int V_\lambda W_{\lambda\, FT} d\lambda$) an increase of 60% in scotopic effective intensity for the incandescent light (2850°K) will scotopically match a 26% decrease in the scotopic effective intensity from the flashtube. Put another way, the scotopic intensity of the flashtube will be $\frac{1.60}{0.74} = 2.15$ times the scotopic intensity of the incandescent light when their photopic intensities are the same. In the scotopic realm, the 100 cd-sec flashtube flick will be 2.15 times as bright as the 809 candela square-pulse 0.3 second incandescent flash. While photopically they both have 476 candela I_e, their effective scotopic intensities would be K/K' times as great, or 298 for the incandescent and 644 for the flashtube.

In peripheral vision, therefore, the flashtube will be more conspicuous than the incandescent flash even though they are both equally effective at photopic threshold. Since the lights in the scotopic realm cannot be fixated to take a bearing, this result of the duality of the retina is inconsequential to normal marine signalling. It would seem, however, that in a search situation where no bearing taking is required but general directional information obtainable in peripheral vision is of importance, in the case used of a 15,000°K light and a 2850°K light, a distinct advantage of a factor of 2.15 in favor of the flashtube can be expected.

Consider a fog of large particles (such that scattering is essentially wavelength independent), and the eye is dark adapted to a point such that the scotopic threshold is 1/50th of the photopic threshold. For a transmissivity of 0.01, from Allard's Law; $E_t = 0.67$ s.m.-c = $\frac{I_e T^D}{D^2} = \frac{476 \times .01^D}{D^2}$, we find a photopic range of 1.3 nautical miles. It is expected that this fog, through forward scattering, will apparently enlarge the source such that while fixated, the outer portion of the "enlarged" source surrounds the fovea in the parafovea with the scotopic sensitivity.

In the scotopic annulus, $E_{tscot} = \frac{E_{tphot}}{50} = 0.0134$ s.m.-c, $I_{e\ INC} = 258$, and $I_{e\ FT} = 644$. We expect to see the incandescent light scotopically, including the annulus surrounding the central photopic fixation point, (by solving $0.0134 = \frac{298 \times .01^D}{D^2}$), for D = 1.90 miles. Similarly, for the flashtube (from $0.0134 = \frac{644 \times .01^D}{D^2}$), we find D = 2.04 miles.

In this case just given, the flashtube can be seen peripherally almost seven percent further away than can the incandescent. The incandescent is visible scotopically 46% further than photopically, and flashtube 57% further scotopically.

Due to the transcendental nature of Allard's Law, no simple solution is easily given for this relationship. It can be stated that the effect increases with a decrease in intensity, an increase in E_t scotopic, and with the ratio of the K's for the two sources. The greater conspicuity of the flashtube in fog is (at least partially) directly attributable to the Purkinje effect of the duality of the retina.

As a final extreme example, consider a fog in which I_e of the lights is 40, the threshold is 10 s.m.-c due to ambient illumination, and $T = 10^{-8}$. The scotopic ranges are 0.216 and 0.246 miles for the incandescent and the flashtube. This is a 14% increase in this case for the flashtube.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Commandant (DAT) U.S. Coast Guard Headquarters Washington, D. C. 20591	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Evaluation of LS-59 Xenon Flashtube Beacon

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (First name, middle initial, last name)
LCDR J. TERRENCE MONTONYE, USCG
LCDR GUY P. CLARK, USCG

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
2 December 1970	105	10

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 712999/004 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Research and Development U.S. Coast Guard Headquarters Washington, D. C. 20591

13. ABSTRACT

Condenser-discharge beacons capable of operation from battery power supplies on buoys and minor lights offer four distinct advantages over incandescent beacons: (1) increased servicing periods, (2) increased battery life, (3) increased visual effectiveness, and (4) increased "glow ranges" in fog. This report presents the laboratory and field test results of the LS-59 flashtube beacon, as well as a discussion of the potential use of condenser-discharge burst lights as a future base for a maritime signal lighting system.

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Security Classification